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Interference Alignment with Partial CSI Feedback in MIMO Cellular Networks

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ABSTRACT:

Interference alignment (IA) is a linear precoding strategy that can achieve optimal capacity scaling at high SNR in interference networks. However, most existing IA designs require full channel state information (CSI) at the transmitters, which would lead to significant CSI signaling overhead. There are two techniques, namely CSI quantization and CSI feedback filtering, to reduce the CSI feedback overhead. In this paper, we consider IA processing with CSI feedback filtering in MIMO cellular networks. We introduce a novel metric, namely the feedback dimension, to quantify the first order CSI feedback cost associated with the CSI feedback filtering. The CSI feedback filtering poses several important challenges in IA processing. First, there is a hidden partial CSI knowledge constraint in IA precoder design which cannot be handled using conventional IA design methodology. Furthermore, existing results on the feasibility conditions of IA cannot be applied due to the partial CSI knowledge. Finally, it is very challenging to find out how much CSI feedback is actually needed to support IA processing. We shall address the above challenges and propose a new IA feasibility condition under partial CSIT knowledge in MIMO cellular networks. Based on this, we consider the CSI feedback profile design subject to the degrees of freedom requirements, and we derive closed-form trade-off results between the CSI feedback cost and IA performance in MIMO cellular networks.

I. INTRODUCTION:

It is well known that inter-cell interference is one of the most important performance bottlenecksin wireless networks. There are many works on interference mitigation techniques and conventional approaches either treat interference as noise or rely on interference avoidance by means of channel orthogonalization [1]. However, these schemes are far from optimal [2]. Recently, interference alignment (IA) was proposed as an effective means to mitigate interference in K-user interference channels [3], [4]. By aligning the interference from different transmitters (Txs) into a lower dimensional subspace at each receiver (Rx), IA can achieve the optimal capacity scaling with respect to (w.r.t.) SNR. As such, there is a surge in the research interest of IA and it has been extended to other topologies such as MIMO cellular networks in [5], [6]. Despite the fact the IA can achieve substantial throughput gain, conventional IA designs [3]–[6] require full channel state information at the Tx side (CSIT). Such full CSIT requirement is quite difficult to achieve in practice due to limited CSI feedback capacity in the reverse link in practice. As such, naive IA design will be very sensitive to CSIT errors [7], [8] and it is important to take into account the CSI feedback constraint in the IA design. There are, in general, two ways to reduce the CSI feedback overhead, namely CSI quantization and CSI filtering. In [7], [8], the authors considered using Grassmannian codebooks to quantize and feedback the channel direction information (CDI) for IA processing. In [9], [10], some adaptive quantization schemes are proposed to exploit the channel statistics so as to enhance the limited CSI feedback efficiency.

However, these schemes considered CSI quantization of the full CDI in the interference networks only. In fact, full CDI may not always be needed to achieve IA processing at the Txs. We illustrate two examples in which substantially reduced CSI is fed back to achieve IA processing. Furthermore, the CSI quantization and the CSI filtering techniques are complementary to each other and in some situations, the CSI filtering will be a first order contributor towards enhancing the CSI feedback efficiency in MIMO cellular networks. The CSI filtering techniques to reduce feedback overhead are relatively less explored. In [11], a CSI filtering scheme by CSI truncation is proposed to reduce the CSI feedback in MIMO interference network. In [12], a CSI filtering scheme with zero-forcing IA is proposed to eliminate the intercell CSI feedback in MIMO cellular networks. However, a more systematic understanding is still needed to determine how much CSI feedback is required for IA processing.

In this paper, we propose a systematic framework of CSI filtering and analyze the associated tradeoff between CSI feedback cost and IA degrees of freedom (DoF) performance in MIMO cellular networks. There are several unique March 18, 2014 DRAFT 3 challenges that need to be tackled. _ How to quantify the CSI Feedback Cost? It may be natural to measure the CSI feedback cost in MIMO cellular networks in terms of the total number of the feedback bits. However, this metric mixes the CSI filtering and CSI quantization together. To obtain some key design insights, it is desirableto have a metric that can solely focus on the CSI filtering aspect because the CSI quantization is complementary and can always be considered on top of the CSI filtering as in Figure 1. _ IA Feasibility Conditions under Partial CSI Feedback: It is well known that the IA scheme is not always feasible and the feasibility conditions are topology specific. The IA feasibility condition is studied for MIMO interference channels in [13]–[16], and for MIMO cellular networks in [17]. However, these works have assumed full CSIT1and hence the precoders can be designed as a function of the full CSI. While in MIMO cellular networks with CSI feedback filtering, the precoders can only be designed based on the partial CSI knowledge from CSI feedback filtering and hence the IA feasibility conditions are different. _ CSI Feedback Design: Further, it remains a question what is the CSI filtering scheme with the least amount of CSI feedback overhead to support the required IA DoFs for a given antenna configuration.

Such a question involves minimization of the CSI feedback cost subject to IA feasibility constraint. However, this problem is highly non-trivial because of the combinatorial nature of CSI filteringscheme design. In this paper, we will address the challenges above as follows. We first define a novel CSI feedback cost metric, namely the CSI feedback dimension. The CSI feedback dimension enables us to isolate the CSI quantization effects from the CSI filtering design so as to obtain tractable and first order design insights. Based on the proposed metric, we propose the idea of IA processing under partial CSI feedback in MIMO cellular networks. After that, we investigate the feasibility conditions and derive the associated precoder / decorrelator solutions for IA under a given partial CSI feedback scheme. Based on these results, we attempt to find out the least amount of CSI feedback overhead by formulating the problem of minimizing CSI feedback dimension subject to IA constraints with a given IA DoFs in the network for a given antenna configuration.

Using specific insights from the problem, we derive a low complexity asymptotically optimal solution and obtain closed-form tradeoff results between the number of DoFs and the CSI feedback dimension. Finally, we compare the proposed IA design with various state-of-the-art 1For instance, in conventional IA formulation [13]–[16], the IA precoders / decorrelators fVi;Ui : 8ig are found to be a function of the entire CSIs fHji : 8j; ig such that rank

II. SYSTEM MODEL
MIMO Cellular Networks:

Consider a MIMO cellular network with G base stations (BSs) and each BS serves K mobile stations (MSs) as illustrated in Figure 2. Consider that each BS and MS are equipped with N and M antennas respectively, and d data streams are transmitted to each MS from its serving BS. We focus on the case when M _ (G1)Kd+d because otherwise, i.e., M > (G1)Kd+d, the number of antennas at the MS is over-sufficient to cancel all the inter-cell interference using pure zero forcing at the MS. Denote the transmit SNR at each BS as P, the k-th MS of BS j as the (j; k)-th MS, the channel matrix from the i-th BS to the (j; k)-th MS as Hjk;i 2 CM_N. The received signal at the (j; k)-th Assumption 1 (Channel Matrices): Assume the elements of Hjk;i are i.i.d. complex Gaussian random variables with zero mean and unit variance. The CSIs are observable at the MSs and the CSI feedback from the (j; k)-th MS will be received error-free by BS j. Furthermore, we assume the BSs f1; _ _ _ ;Gg have backhaul connections such that the feedback CSI can be shared among them. March 18, 2014 DRAFT 5 (a): CSI Filtering (b): Quantization with Grassmannian codebooks (j,k)-th MS BS side Feedback Local CSI IA design Figure 1. Role of CSI filtering in the CSI feedback reduction. B. CSI Feedback Filtering and Feedback Cost The CSI feedback reduction in MIMO cellular networks contains two processes in general, namely the CSI filtering and the CSI quantization as illustrated in Figure 1. To simplify the analysis, we shall consider these two factors separately. We consider CSI filtering only in Sections II-IV (no quantization is performed) and then analyze the effects of CSI quantization (block (b)) in Section V. Since IA processing aims at nulling off interferences at the MS, only the CDI2, i.e., P(Hjk;i) = faHjk;i : a 2 Cg, 8j; k; i, is required to design the IA transceivers. Hence, we shall consider CSI feedback over the Grassmannian manifold The feedback dimension in Def. 2 is a first order measure of CSI feedback cost in MIMO cellular networks because it isolates the contribution of CSI feedback reduction due to CSI feedback filtering from CSI quantization. First, a Grassmannian manifold of dimension D is locally homeomorphic3 to CD_1. Intuitively, this means that a Grassmannian manifold of dimension D locally looks like the D-dimensional Euclidean space and a feedback dimension D means that D scalars are required to feedback to the BS side. Second, the feedback dimension is also directly proportional to the total number of bits allocated for CSI feedback in MIMO cellular networks. As in Theorem 5 in Section V, we demonstrate that with a total number of CSI feedback bits Dlog SNR, it is sufficient to support certain DoF in MIMO cellular networks. C. Interference Alignment under Partial CSI Feedback-One commonly adopted IA formulation in MIMO cellular networks is to find out the precoder and decorrelator solutions fUjk;Vjkg based on the full CSIT knowledge, such that the following set of conditions can be satisfied:

III.EXISTING SYSTEM:

Pilot based channel acquisition method implemented in existing system.CSI feedback system has been implemented based on channel orthogonization system.Sum degrees-of-freedom (DoF) for the static flat-fading multiple input multiple-output (MIMO) interference channel is equivalent to a rank constrained rank minimization (RCRM) problem has been implementedThe rank minimization corresponds to maximizing interference alignment (IA) such that interference spans the lowest dimensional subspace possible. The rank constraints account for the useful signal spaces spanning all available spatial dimensions.

IV.PROPOSED SYSTEM:

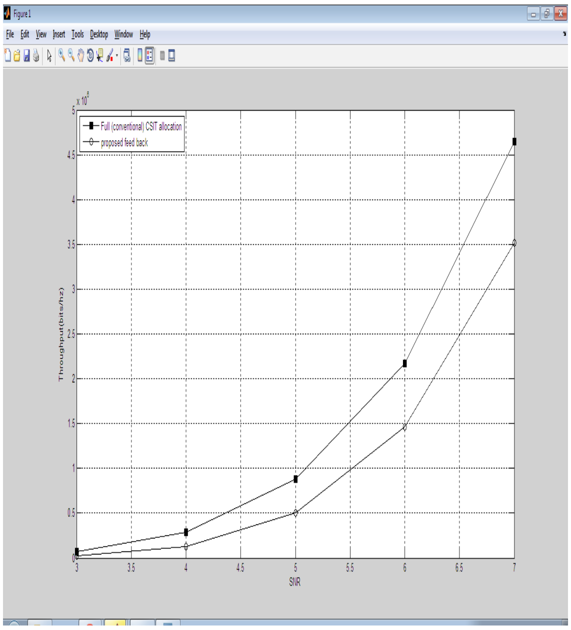
The CSI feedback dimension enables us to isolate the CSI quantization effects from the CSI filtering design we investigate the feasibility conditions and derive the associated precoder/decorrelator solutions for IA under a given partial CSI feedback scheme One commonly adopted IA formulation in MIMO cellular networks is to find out the precoder and decorrelator solution IA processing with CSI feedback filtering in MIMO cellular networks. We characterize the feedback cost by the feedback dimension and demonstrate that it can serve as a first order metric of the CSI feedback overhead.Interference Alignment for Interference Channels When the user's data symbols are not shared between the TXs, the setting is referred to as a Interference Channel (IC) in the communication theoretic literature.

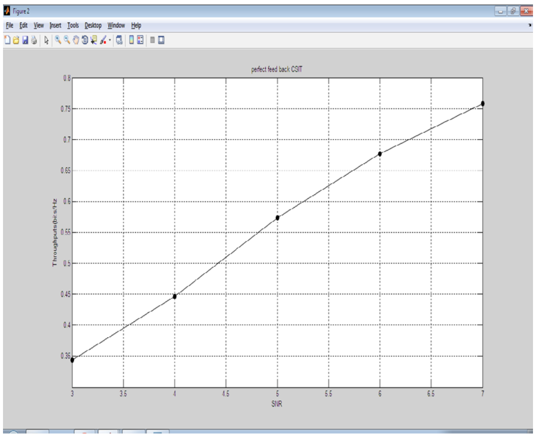
In MIMO ICs, a method called Interference Alignment (IA) has been recently developed and shown to achieve the maximal number of degrees-of-freedom (DoF), or pre-log factor, in many cases [2], [4]. As a consequence, IA has attracted a lot of interest in the community. In this work, we will take the DoF as our key performance metric, such that we focus on IA schemes. IA is said to be feasible if the antenna configuration (i.e. the distribution of antenna elements at the TXs and the RXs) yields enough optimization variables to allow for the interference-free transmission of all user's data symbols, which means fulfilling Intuitively, IA consists in letting the TXs coordinate among themselves to beamform their signalssuch that the interferences received at each of the RXs are confined in a subspace of reduced dimensions, which can then be suppressed by linear filtering at the RXs with a smaller number of antennas.

V.PRECODING IN THE NETWORK MIMO:

When the user's data symbols are shared between the TXs, the TXs form a distributed antenna array and a joint precoder can be applied at the transmit side [3]. Consequently, this setting becomes similar to the single TX multi-user MIMO downlink channel and the interference between the TXs can be completely canceled, e.g., by applying a global ZF precoder T □ H−1 These two scenarios are schematically represented C. Limited Feedback Versus Limited Sharing The limited feedback capabilities have been recognized as a major obstacle for the practicalmuse of the precoding schemes described above. Consequently, a large literature has focused on this problem and both efficient feedback schemes and robust transmission schemes have beennderived, for Network MIMO and IA Yet, all these works assume that the imperfect channel estimates obtained via limited feedback are perfectly shared between all the transmit antennas. This is a meaningful assumption when the TXs are colocated but less realistic otherwise, as we shall now see. CSIT Sharing Issues: One obstacle to the sharing of global CSIT follows from the fact that the amount of CSI which has to be exchanged increases very quickly with the number of TXs. In fact, each TX needs to obtain the CSI relative to the full multiuser channel, which consists of (NK) scalars in a K-user setting with N antennas at each node. In addition, acquiring the CSI at a particular TX can be realized either by a direct broadcast of the CSI to all the listening TXs or by an over-the-air feedback to the home base station alone, followed by an exchange of the local CSIs over the backhaul, as it is currently advocated by 3GPP LTE-A standards See the illustrations for such scenarios Note that exchange over the backhaul can involve further quantization loss and may lead to a different CSI-aging at each TX, due to protocol latency. Either case, the channel estimates available at the various TXs will not be exactly the same. This leads to a form of CSI discrepancy which is inherent to the cooperation among non-colocated TXs. In order to capture multiple-antenna precoding scenarios whereby different TXs obtain an imperfect and imperfectly shared estimate of the overall multi-user channel, we denote by nH(j) the network-wide channel matrix estimate available at TX j. Consequently, the precoding schemes in Figure 1 have to be modified to take into account that each TX will compute its precoder based on its own channel estimate. Thus, TX j transmits xj = T(j)s based on the knowledge of H(j) only. The fundamental questions which arise are: (i) how complete and accurate should the estimate H(j) be for each j while operating under reasonable CSI overhead constraints? and (ii) how should precoders be designed given the likely discrepancies between various channel estimates? Although these questions prove to be difficult and to a large extent remain open, we shed some light on the problem for two key scenarios in the following sections.

VI. SIMULATION RESULTS:





ADVANTAGES:

1.Optimal through put
2.CSI at transmitter side
3. Limited CSI feedback efficiency
4. Reducing overhead

FUTURE SCOPE:

Combining multiple-input multiple-output orthogonal frequency division multiplexing (MIMO-OFDM) with a massive number of transmit antennas (massive MIMO-OFDM) is an attractive way of increasing the spectrum efficiency or reducing the transmission energy per bit. The effectiveness of Massive MIMO-OFDM is strongly affected by the channel state information (CSI) estimation method used. The overheads of training frame transmission and CSI feedback decrease multiple access channel (MAC) efficiency and increase the CSI estimation cost at a user station (STA). This paper proposes a CSI estimation scheme that reduces the training frame length by using a novel pilot design and a novel unitary matrix feedback method.

CONCLUSIONS:

Interference channels, where multiple transmit and receive user pairs communicate using the same radio resources, are a building block of wireless networks. The interference channel is a good model for communication in cellular networks, wireless local area networks, and ad-hoc networks. Conventional thinking about the interference channel is that each user pair has no information about other usersinthe network and therefore its optimum strategy is to be greedy and maximize its own rate.

Unfortunately, the sum of the data rates achieved across all user pairs with this strategy is of the same order as the rate of a single communication link. Recent work on the interference channel by however, has shown that sum rates can scale linearly with the number of users at high SNR, using a transmission strategy known as interference alignment. Interference alignment is a linear precoding technique that attempts to align interfering signals in time, frequency, or space. In MIMO networks, interference alignment uses the spatial dimension offered by multiple antennas for alignment. The key idea is that users coordinate their transmissions, using linear precoding, such that the interference signal lies in a reduced dimensional subspace at each receiver. Allowing some coordination between transmit and receive user pairs enables interference alignment. In this way, it is possible to design the transmit strategies such that the interference aligns at each receiver. From a sum rate perspective, with K user pairs, an interference alignment strategy achieves a sum throughput on the order of K/2 interference free links! Basically each user can effectively get half the system capacity. Thus unlike the conventional interference channel, there is a net sum capacity increase with the number of active user pairs. This result has special importance in cellular and ad hoc networks, showing that coordination between users can help overcome the limiting effects of interference generated by simultaneous transmission.

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