Massive MIMO Inspired 2-Stage Design of the Multi-Cell Multi-User MIMO Downlink

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Abstract—**The Interfering Broadcast Channel (IBC) applies to the downlink of (cellular and/or heterogeneous) multi-cell networks, which are limited by multi-user (MU) interference. The interference alignment (IA) concept has shown that interference does not need to be inevitable. In particular spatial IA in the MIMO IBC allows for low latency. However, IA requires perfect and typically global Channel State Information at the Transmitter(s) (CSIT), whose acquisition does not scale well with network size. Also, the design of transmitters (Txs) and receivers (Rxs) is coupled and hence needs to be centralized (cloud) or duplicated (distributed approach). CSIT, which is crucial in multi-user systems, is always imperfect in practice, especially for the intercell links. We consider mean and covariance Gaussian partial CSIT. We focus on the optimization of beamformers for the expected weighted sum rate (EWSR) under per BS power constraints. We apply a perfect CSI technique, based on a difference of convex functions approach, to a number of deterministic approximations of the EWSR, involving the Massive MIMO (MaMIMO) limit (large number of transmit antennas), and the large MIMO limit (both large transmit and receive antenna numbers). We then focus on distributed techniques that exploit local CSIT, feedback of a limited number of scalars and vectors, and only one or few iterations.**

I. INTRODUCTION

In this paper, Tx may denote transmit/transmitter/ transmission and Rx may denote receive/receiver/reception. Interference is the main limiting factor in wireless transmission. Base stations (BSs) disposing of multiple antennas are able to serve multiple Mobile Terminals (MTs) simultaneously, which is called Spatial Division Multiple Access (SDMA) or Multi-User (MU) MIMO. However, MU systems have precise requirements for Channel State Information at the Tx (CSIT) which is more difficult to acquire than CSI at the Rx (CSIR). Hence we focus here on the more challenging downlink (DL). The overhead required for this global distributed CSIT is substantial, even if done optimally, leading to substantially reduced Net Degrees of Freedom (DoF) [1].

The multi-antenna interference management approach we advocate here is one of (2-sided) coordinated beamforming (CoBF). This differs from Coordinated MultiPoint (CoMP) in that CoMP furthermore requires joint acces by multiple BS to the signals to be transmitted. Hence, CoBF applies much more easily to Hetnets, in which a high speed low latency backhaul for CoMP is difficult to put in place. Though CoBF does not require signal exchange, 2-sided CoBF still requires (in principle global) high precision CSIT, which represents a lot of information, that needs to be updated at fast fading rate. Esp. the latency requirements are not very compatible with typical cloud networking operation. The CSIT exchange can be implemented by exploiting the interfering connectivity to exchange wirelessly in the control plane of a **fog networking** approach [2].

The recent development of Massive MIMO (MaMIMO) [3] opens new possibilities for increased system capacity while at the same time simplifying system design. From a DoF point of view it may seem like a suboptimal use of antennas. However, as shown in [4], section V, Fig. 6, the (MaMIMO asymptotics based analytical expression for the) optimal number of users decreases below the DoF as the SNR decreases. Furthermore, Net DoF considerations and CSI acquisition make the optimal number of users decrease further. In [5], [6], MISO was considered in a single cell. Statistical CSIT between user groups was considered and instantaneous CSIT within user groups. The hypothesis is that some users overlap strongly in terms of covariance subspaces but not in terms of instantaneous CSIT. In [7] a hierarchical approach is considered.MISO is considered and (high SNR based) user selection also. Intercell zero-forcing (ZF) beamforming (BF) is considered based on statistical CSIT, treating interfering links in a binary fashion (either ZF or ignore). Intracell BF is based on instantaneous CSIT and performs Regularized-ZF, which is claimed to be asymptotically optimal (which is only true for uniform user power profile). In [8], following up on work in [9], beamspace processing is proposed, which is the basic form of hierarchical BF. As argued in [6] also, mmWave communications, which we target here also, facilitate MaMIMO, and lead to a limited number of dominant paths as they approach optics.

What is known as MaMIMO is more appropriately called MU Massive MISO whereas here we consider actual MU MC MaMIMO. In this paper the objective is to find the set of beamforming (BF) vectors that maximize the Weighted Sum Rate (WSR) of the IBC network. In [10] the alternative problem formulation of SINR balancing is considered.

The contributions here are significantly better partial CSIT approaches compared to the Expected Weighted Sum MSE (EWSMSE) approach in [11] (which cannot even be used in the zero channel mean case), and to present deterministic alternatives to the stochastic approximation solution of [12]. We treat the Gaussian CSIT case. The goal here is to go beyond the extreme of zero-forcing (ZF) and to introduce a meaningful beamforming design at finite SNR and with partial CSIT, for e.g. a finite Ricean factor when not much more than the (location based) LoS information of the intercell links is available at the BS. The other goal is to arrive at distributed approaches in which global CSIT (channels from all BS) gets replaced by local CSIT (channels from own BS only) plus feedback of a limited number of scalars, as in [13], [14]. However, the design of MIMO systems, as opposed to MISO systems, complicates distributed designs if one wants to keep the feedback low. Another issue is to keep the number of iterations low, for performance and feedback considerations.

Over the last year or so, a number of research works have proposed to exploit the channel hardening in Massive MIMO to reduced global instantaneous CSIT requirements to local instantaneous CSIT plus global statistical CSIT. However, this only works for MISO systems in which all the work needs to be done by the transmitters. In the case of MIMO, in which UEs possess a limited number of antennas which contribute actively (e.g. to ZF/IA at high SNR), the interference subspace and hence the receiver at the UEs does not harden. In this paper, we exploit the fact that the overall ZF/IA work can be split in different ways between Tx/Rx in an IBC network to let the Rx focus on intracell interference management, whereas intercell interference gets handled by the Tx. Massive MIMO arguments lead us then to propose a two stage approach. In the first stage a cell-wise (intracell) joint Tx/Rx design gets performed based on local CSIT. The Rx then get fixed and exchanged for the second stage of global Tx design in which the MIMO channel - MISO Rx cascades become equivalent MISO channels.

II. 2-STAGE IBC DESIGN

The CSIT setting considered here is high quality (high Ricean factor) intracell CSIT and Tx covariance only intercell CSIT. For what follows we shall assume the LoS Tx intercell CSIT. We shall focus on a MaMIMO setting. The approach considered here is non-iterative, or could be taken as initialization for further iterations.

1) Iteration 0*:* To properly gauge the intercell interference caused by the other BS, we shall start with a per cell design. In the case of multiple Tx and Rx antennas, different WSR local optima correspond at high SNR to different distributions of the zero forcing (ZF) roles between the various Txs and Rxs. To simplify design, we shall assume here that Rx antennas are used to handle intracell interference. Hence all intercell interference needs to be handled by Tx (BS) antennas. In that case, the crosslinks (cascades of channel and Rx) can be considered as independent from the intracell channels. In a MaMIMO setting, the ZF by BS j towards $K - K_j$ crosslink channels (or LoS components in fact) will tend to have a deterministic effect of reducing the effective number of Tx antennas by this amount and hence of reducing the Tx power by a factor $\frac{M_j}{M_j-(K-K_j)}$. Hence a per BS design can be carried out with (partial) intracell CSIT, with BS Tx power P_j replaced by $\frac{M_j}{M_j-(K-K_j)}P_j$, and with all intercell links $\mathbf{H}_{k,b_i} = 0$, $b_i \neq b_k$. The power reduction factor considered corresponds to ZF or hence a high SNR assumption. At a finite SNR, the user k SINR reduction will be less because the optimal BF would do some regularized ZF of intercell interference caused, but the SINR would on the other hand be smaller because the intercell interference is not ZF'd. We shall assume that these two opposite effects roughly compensate each other. This first step (which is itself an iterative design for the scenario considered with reduced Tx power and no intercell links) leads to BFs $\mathbf{g}^{(0)}$.

2) Iteration 1*:* The idea is now to do one iteration in order to adjust the Tx filters for the intercell interference. So, with the initial BFs $\mathbf{g}^{(0)}$, the local intercell CSIT $\mathbf{C}_{t,i,b_k}$ also, the correct power constraints, and the various received interference covariance matrices, the quantities required for a difference of convex functions approach [15] can be determined. The only information that needs to be fed back from user i in another cell is a positive scalar. This is related to the interference pricing in game theory [14]. The normalized BFs and the stream powers can then be computed. See http://www.eurecom.fr/en/publication/4469 for more information.

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