Pilot Contamination in Massive MIMO: Virtual Angular Information aided Channel Estimation

Andrea P. Guevara, Cheng-Ming Chen, Sofie Pollin
Department of Electrical Engineering, KU Leuven, Belgium
{aguevara,cchen,spollin}@esat.kuleuven.be

***Abstract*—In a Massive MIMO (Multiple Input Multiple Output) system the base station needs accurate channel state information (CSI). However, the accuracy of CSI estimation is highly impacted by pilot contamination. Different channel estimation solutions mitigate pilot contamination by presuming clean and not contaminated channel covariance matrices. Nevertheless, obtaining such covariance matrix or statistics about the real CSI is difficult in practice under pilot contamination conditions. In this paper, we propose a method using virtual angular transformation (VAT) to separate contaminated channels, by exploiting location dependent channel statistics in combination with minimum mean square error (MMSE) channel estimation. When the users are in different locations our results show 10dB reduction of the channel estimation error compared to zero-forcing.**

I. Motivation

The quality of the channel estimation plays a critical role to mitigate inter-user-interference in any Massive MIMO system. In the case of time-division-duplex schemes, channel estimation is realized during uplink (UL) training, where each user sends a known orthogonal pilot over its channel to the BS. With this pilot, a BS can estimate the UL and subsequently downlink (DL) channel relying on channel reciprocity [1].

Due to a finite coherence time and bandwidth, the length of a sequence and hence the number of orthogonal codes in a codebook is limited. To minimize the overhead of the channel estimation, two or more users have to share the same pilot sequence. However, when two adjacent cells use the same pilot sequence it leads to inter-user-interference in the channel estimation, which is called pilot contamination (PC).

In [2], a summary of methods to mitigate PC is introduced. Most methods rely on the covariance matrix to mitigate interference. However, this matrix is difficult to obtain if the channel is already contaminated.

II. Methodology

In this work we propose a novel channel estimation method, which uses the virtual angular transformation (VAT) to separate channels from multiple interfering users under PC conditions. Our method first estimates covariance matrices based on the information of each separate channel and then applies minimum mean square error (MMSE). This method is applied for a channel that is already contaminated.

In our simulation results, two users are considered that belong to the same system and transmit the same pilot sequence from different locations. Each channel is modeled as a discrete physical channel, containing multiple paths as steering vectors. VAT is applied over the signal at the receiver, and it is able to decontaminate and estimate the channels for both users using MMSE. In contrast with [3], where the covariance matrix is calculated from the channel state information and location of each user, our work proposes a more realistic approach when channel statistical information is difficult to obtain.

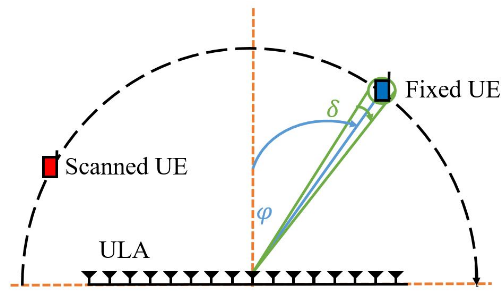

Fig. 1. Scenario: A system with two users, during UL training send the same pilot sequence to the BS which is equipped with a ULA. One user stays in a fixed location, while the second one moves surrounding the BS.

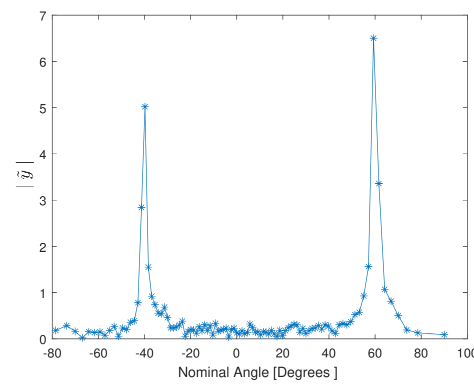

Fig. 2. Virtual representation of the signal at the receiver under pilot contamination conditions, projected over physical nominal angles. For users with 40° and 60° as nominal angle

A. Channel separation

In a system with PC, the signal at the receiver contains information from both the desired and interfering user. To obtain clean channel covariance matrices for channel estimation, VAT is applied to the signal at the receiver $\mathbf{y}$. See Fig. 2.

$$\tilde{\mathbf{y}} = \tilde{\mathbf{A}}_R{}^H \mathbf{y}. \tag{1}$$

If the Angles of Arrival (AoA's) of both user's channels don't overlap, we can eliminate the Virtual Angles (VAs) that contain interference from the *j*th user, replacing those VAs with zeros.

$$\dot{\tilde{\mathbf{h}}}_k(\tilde{\vartheta}) = \begin{cases} 0 & \text{when} \quad \tilde{\vartheta} \in (\varphi_j \pm \alpha\delta_j), \quad k \neq j \\ \tilde{\mathbf{y}}(\tilde{\vartheta}) & \text{else} \end{cases} . \tag{2}$$

The aim of this method is to preserve VAs for the desired channel while the contaminated ones are removed. Therefore, a tradeoff metric α is introduced, to control the amount of VA filtering. On one hand, if the difference of the users' nominal angles is big and α is large, (2) filters a large number of of VAs, surrounding the nominal and spread angles of the interference. However, if α is large it will also eliminate multipath information of the desired channel. On the other hand, when the users are close to each other (a small difference in their nominal angle), the decontaminated VAT parameter should be set to a small value, to filter just the VAs of the interfering channel.

Once the channels are separated, an inverse virtual angular transform is applied to each VA to obtain the physical representation of both users channel.

$$\dot{\mathbf{h}}_k = \tilde{\mathbf{A}}_R \dot{\tilde{\mathbf{h}}}_k. \tag{3}$$

B. MMSE-based channel estimation

At this point, an instantaneous decontaminated channel is obtained, which can be used to calculate each user's covariance. Subsequently, the MMSE channel estimation is applied.

$$\dot{\mathbf{R}} = \frac{1}{S} \sum_{s=1}^{S} \dot{\mathbf{h}}[s] \dot{\mathbf{h}}^H[s]. \tag{4}$$

III. Numerical Results

In order to preserve fairness between the two users, the transmit power and path loss are normalized. The remaining parameters are presented in Table I.

TABLE I
Simulation Parameters

Signal to Noise Ratio (SNR)	20 dB
Antennas number (M)	100
Antennas spacing	1/2
Number of paths (N)	500
Angular spread (δ)	1°
Decontaminated VAT parameter (α)	10
Pilot length (τ)	1

A comparison between different channel estimation techniques considering only pilot contamination is shown in Fig. 3. The ideal MMSE channel estimation, with a complete information of the covariance matrix gives the best NMSE for

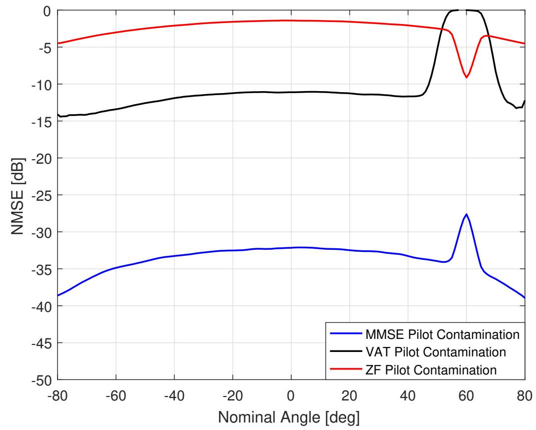

Fig. 3. NMSE vs Scanned UE Nominal Angle for different channel estimations, with a Fixed UE in 60°, and $\alpha = 10$

the scanned UE. Zero-Forcing (ZF) is also analyzed, which estimates the channel from the signal information at the receiver only. Our proposed VAT method has a better performance than ZF and also relies on the information obtained from the signal at the receiver.

Based on the premise that a channel is contaminated for a large period of time, each covariance matrix to be used in the MMSE method could not be calculated, therefore our method provides a very good channel estimation for contaminated channels in comparison with ZF. However, when contaminated channels are overlapped in nominal and spread angle, α must be adjusted to get better results (α is fairly large in Fig. 3).

IV. Conclusion

This work presents a novel solution to decontaminate and estimate the channels for two users under pilot contamination conditions. The proposed method uses virtual angular transformation to separate interfered channels according to AoA, and based on this information an MMSE channel estimation is applied. The results show a decrease of the normalised channel error with 10dB for a large range of positions as confirmed for our simulations, in comparison with ZF.

Acknowledgment

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