Chapter 1

The Pilot Contamination problem

AUTHOR NAME (CRISTINA GAVA)
STUDENT ID 1155449

1.1 Overview

Compared to existing cellular network infrastructures, nowadays there is an increasing need for technologies providing higher capacity. This comes from an always bigger demand for higher data rates in wireless mobile communication systems such as Internet if Things (IoT), Machine to Machine (M2M) communication and other electronic services.

The current 4G cellular networks, 3rd Generation Partnership Program (3GPP) above all, were designed with the intention to support a peak spectral efficiency of 15 bps/Hz, a bandwidth of 100 MHz and an ultra-low latency [1]. Nonetheless, the estimated future traffic far exceeds the resources of the current 4G and so the need for 5G cellular networks.

One of the novelties of the 5G protocol which is beeing designed and refined in the present communication scenario is the Multiple-input Multiple-output (MIMO) system, a technology that focuses on the idea of implementing multiple antennas terminals in one device - or Base Station (BS) - in order to enhance the quality and reliabilty of communication. Without going into details, one of the options for this system is the multiuser MIMO system, where and array of antennas serves a group of autonomous terminals at the same time. These terminals may be single-antenna cheap devices and the multiplexing throughput gains are shared among the User Terminal (UT)s

[2].

In this type of system, the Channel State Information (CSI) has a crucial role, since forward-link data transmission needs that the base station know the forward channel, as well as the reverse-link data transmission require it to know the reverse channel. This is the reason why such things as pilot signals exist, but with them some problems might arise due to the contamination of such signals. What we mean to takle in this chapter is exactly to have a detailed look at those kind of problems, referred to as pilot contamination, and at a couple of main approaches to solve them.

1.2 The pilot contamination problem

In several works multi-user MIMO operations with a big excess of base station antennas are considered: in them the channel is estimated exploiting the feedback or channel reciprocity schemes through multiplexing over frequency - Frequency Division Duplex (FDD) - or over time - Time Division Duplex (TDD). In TDD a time-slot, over which the channel can be thought as constant, is divided between reverse-link pilots and forward-link data transmission. The pilots assume reciprocity to provide the BS with an estimate of the forward channel, which in turn generates a linear pre-coder for data transmission [2]. In the FDD scenario, the division is made over the frequency and the system requires not only the estimation, but also feedbacks for both forward and reverse direction between the BS and the UT.

For this reason TDD is considered a more suitable approach the FDD when it comes to acquiring CSI in wireless systems [1] and following this line, we will focus on this system.

In TDD the time pilots require is proportional to the number of terminals served, while the number of base station antennas does not influence it. At the same time, though, the number of terminals that can be served is limited by the coherence time. One of the principal findings in this sense, is that the addition of BS antennas always brings benefits to the SNR situation.

To simplify the observed scenario, several works focus on multi-user MIMO operations with an infinite number of base station antennas in a multicellular environment. In this frame, orthogonal pilots would need length of at least $K \times L$ symbols (with $K =$ overall number of UTs in a cell and $L =$ total number of cells in a system) due to frequency reuse factor of one, so non-orthogonal pilots across neighboring cells are used. At the same time, the use of $K \times L$ pilots is not feasible beacuse of short channel coherence times due to UTs mobility [1]. Because of it, the problem of pilot contamination arises and it has been considered one of the main impirments in massive MIMO systems.

1.2.1 UL training

The use of pilot in the TDD scheme is related to the Uplink segment training. Considering the worst-case scenarion in this means assuming that all UTs transmit synchronous pilot sequences of length τ symbols at the beginning of every coherence interval. Every cell then transmits a $\tau \times K$ orthogonal matrix $\mathbf{S}_j = (\mathbf{s}_{j1}, \ldots, \mathbf{s}_{jk})$ which satisfies $\mathbf{S}_j^T \mathbf{S}_j = \tau \mathbf{I}$. The received signal matrix at the l_{th} BS is then:

$$\mathbf{Y}_l = \sqrt{p_u} \sum_{j=1}^{L} \mathbf{D}_{l,j}^{1/2} \mathbf{H}_{l,j} \mathbf{S}_j^T + \mathbf{N}_l \tag{1.21}$$

with:

- $\mathbf{N}_l$ = the $M \times \tau$ additive noise matrix whose elements are are i.i.d. zero mean, circularly-symmetric complex gaussian $\mathbb{CN}(0,1)$ random variables;

- p_u = the average transmit power at each user on the uplink;

- $$\mathbf{D}_{l,j} = \begin{bmatrix} \beta_{l,1,j} & & \\ & \ddots & \\ & & \beta_{l,K,j} \end{bmatrix} \tag{1.22}$$
  with $\beta_{l,k,j}$ being the large scale fading coefficient;

- $$\mathbf{H}_{l,j} = \begin{bmatrix} h_{l,1,j,1} & \ldots & h_{l,k,j,1} \\ \vdots & \ddots & \vdots \\ h_{l,1,j,M} & \ldots & h_{l,k,j,M} \end{bmatrix} \tag{1.23}$$
  with $h_{l,k,j,m}$ being the small scale fading factor whose variables are $\mathbb{CN}(0,1)$.

(Cri says: Cita paper marzetta e paper prof per i diversi tipi di contaminazione)

1.3 The connection with 5G protocol

(Cri says: Cita paper 5th e paper del prof)

1.4 The approaches

(Cri says: cita paper del prof)

1.5 Pilot reuse approach details

(Cri says: non ricordo paper)

1.6 Subspace estimation approach details

(Cri says: cita paper muller)

1.7 Conclusions

Example of use of bibliography [2]

Bibliography

[1] O. Elijah, S. Member, C. Y. Leow, T. A. Rahman, S. Nunoo, and S. Z. Iliya, "A Comprehensive Survey of Pilot Contamination in Massive MIMO — 5G System," *IEEE Communications Surveys & Tutorials*, vol. 18, no. 2, pp. 905–923, 2016.

[2] T. L. Marzetta, "Noncooperative Cellular Wireless with Unlimited Numbers of Base Station Antennas," *IEEE Transactions on Wireless Communications*, vol. 9, no. 11, pp. 3590–3600, 2010.