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Estimation of the 5G Massive-MIMO Antenna Beams using Drones by Minimum Trace Norm Minimization

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Abstract

The use of drones to measure the pattern of the antenna in situ and in operative conditions is a very attracting option of 5G m-MIMO (massive-MIMO) antenna characterization. However, during the measurement session the pattern rapidly changes covering all the possible beams. This makes the estimation of the patterns less trivial than the case of 4G single beam antennas. In this paper we propose the use of the minimum trace norm approach to restore the patterns from the set of measured data. A simple example regarding 4 beams antenna (3 Traffic Beams and one Broadcast Beam) is discussed.

1 Introduction

5G has opened a new era for non-military antenna market. For the first time the huge potentiality of active arrays has been investigated in the framework of personal communication systems, and today AAS (Active Array Systems) are deployed all overthe world on 5G base stations. While the flexibility in terms of patterns represent a great advantage compared to 'classic' antennas used in the previous generation of cellular systems, they represent a formidable challenge in terms of antenna characterization.

In order to clarify the problems regarding the antenna characterization, let us consider a 5G antenna as it is currently designed. The antenna is designed to radiated a large number of different patterns. They range from less directive patterns used for SS/PBCH (Syncronization Signal/Physical Broadcast Channel) trasmission, called Broadcast beams, to high directive pattern users for the PDSCH (Physical Downlink Shared Channel) transmission, called Traffic beams [1]. In the currently deployed solution both the Broadcast beams and Traffic beams belong to sets of possible patterns (called 'grid of beam'). The Broadcast beams are periodically transmitted, and are easily identificable. Instead, the Traffic beams are associated to the traffic of the users.

Each Traffic beam is associated to an index identifying a set of pre-coded beams available at the base station. However, a specific beam is neither associated to a single user nor to always the same user, but the beams are dynamically selected according to the scheduling of the users and the position of the users, that change in time.

On the other hand, AAS include sophisticated electronic front-end. The absence of 'cables', and hence connectors, between the electric front end and the radiating elements makes impossible the test of the antenna connectors measurement systems at the imput connectors of the antenna, as happens in 4G systems. This forces the use of Over The Air (OTA) test. Among them, there is a special interest toward the use of drones, that allows to measure the pattern of the antenna *in situ* and *in operative conditions*, i.e. keeping the communication system fully operative.

This very attracting solution has some drawback when we use drones in 5G systems. In fact, during the measurement session the pattern rapidly changes covering all the Broadcast and Traffic beams. Data associated to different patterns can be distinguished from the SS/PBCH symbol or from the CSI information, and hence it is possible to divide the total data in N_{beams} set of data, each associated to a specific Broadcast or Traffic beam. The result of this selection process is N_{beams} sets of highly uncomplete data. This makes the estimation of the patterns less trivial than the case of 4G single beam antennas.

In this paper we propose to use the minimum trace norm approach to restore the patterns from uncomplete data. The method has been investigated in the past in the framework of near-field far-field tranfromation in planar and spherical measurement geometry.

This paper describes some preliminary analysis regarding the possibility to use the strategy outlined in papers [2], [3] directly to far-field data acquired on a cylindrical surface.

2 The Method

Let $\mathbf{X} \in \mathbf{C}^{m \times n}$ be the unknown matrix collecting the electromagnetic field radiated by a source on a uniform lattice Ω. This field is measured at p positions of Ω ($p < m.n$) and collected in the vector $\mathbf{e} \in \mathbf{C}^{p}$.
In order to estimate the field on each point of Ω we use the

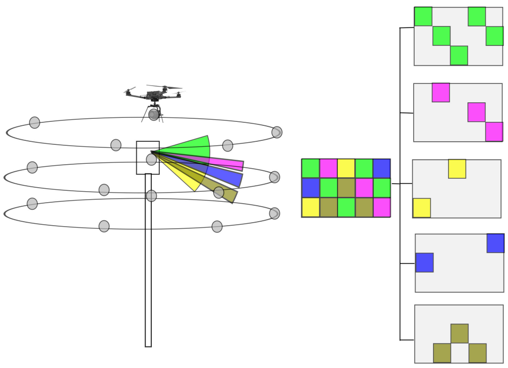

Figure 1. Scheme of measurement with a drone; the figure shows two Broadcast beams and three Traffic beams; the measured data are associated to different patterns of a 5G antenna; when the data of the beams are extracted, each set of data turns out to be uncomplete.

following rank minimization algorithm:

$$\min_{\mathbf{X}\in\mathbf{C}^{m\times n}} \ \operatorname{rank}(\mathbf{X}) \ \text{ subject to } \ \|\mathscr{A}(\mathbf{X})-\mathbf{e}\|_2 \le \varepsilon \tag{1}$$

where $\mathscr{A}$ is the linear map:
$mathbfC^{m\times n} \rightarrow$
$mathbfC^{p}$ that selects the p measured points among the $m.n$ sampling points of Ω, and where the parameter ε depends on the noise level affecting the measured data $\mathbf{e}$.
The problem (1) is known as matrix completion problem. In general, Eq. (1) is a challenging non-convex optimization problem for which all known finite time algorithms have at least doubly exponential running times in both theory and practice. To solve this problem it is possible to follow an heuristic approach that minimizes the nuclear norm $\|\mathbf{X}\|_*$.

Accordingly, the problem (1) can thus be relaxed using the heuristic optimization [3]:

$$\min_{\mathbf{X}\in\mathbf{C}^{m\times n}} \ \|\mathbf{X}\|_* \ \text{ subject to } \ \|\mathscr{A}(\mathbf{X})-\mathbf{e}\|_2 \le \varepsilon \tag{2}$$

Any semidefinite programming solver can be used to find the best solutions of (2). We use the software CVX [4] that calls an interior point optimizer.

3 Example

As proof of concept, we consider a square array antenna radiating 4 beams. The field measured on a half-cyndrical surface is shown in Fig. 2 (right figure). The exact field amplitude of the four patterns are shown in Fig. 3, while the estimated ones obtained form the data shown in Fig 2 (currupted by -40 dB noise level) are shown in Fig.4.

The method can be further improved using an prelimiary step the Thin Plate Spline (TPS) interpolation algorithm [3]. Details can be found in [3].

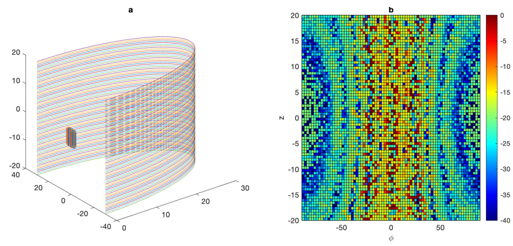

Figure 2. On the left: geometry of the problem; on the right: measured data on the half-cylindrical surface.

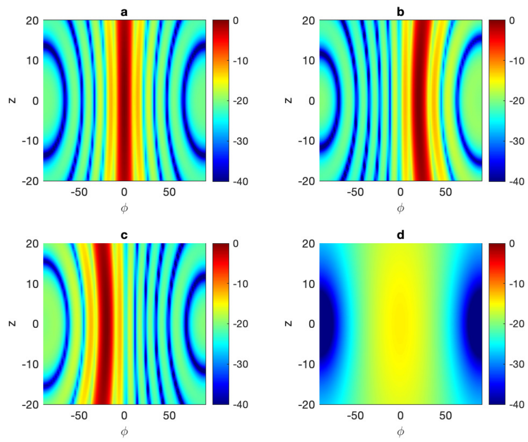

Figure 3. Exact field amplitude of the four beams of the antenna on the half-cylindrical surface; the first three patterns are associated to three Traffic Beams; the fourth (lower right figure) is associated to a Broadcast Beam.

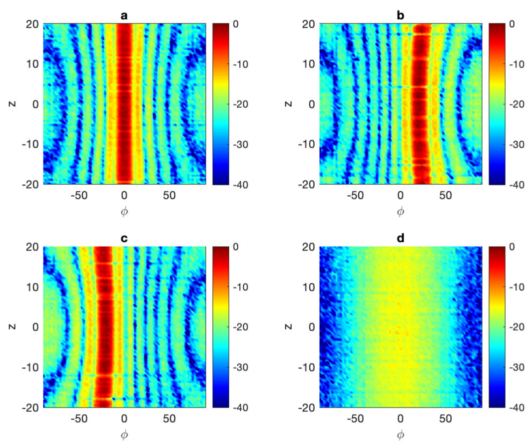

Figure 4. Field amplitude of the four beams of the antenna on the half-cylindrical surface estimated form the measured data currupted by -40 dB noise level.

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