Full-Dimension MIMO Arrays with Large Spacings Between Elements

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***Abstract*—Full-Dimension MIMO is identified as a promising MIMO technique for next cellular standards. It is based on performing beamforming not only in the azimuth but also in the elevation dimension. In this paper, it is studied how the beamforming performance can be enhanced by increasing the spacing between antenna elements. The major claims are that the system capacity can be enhanced by increasing the antenna spacing until the limit in which the grating lobes start falling inside the desired sector. For larger spacings, the benefits of reduced beamwidths are cancelled out by the interference introduced by grating lobes.**

I. INTRODUCTION

Traditionally, base station antennas were based on a set of dual–polarized 45º slanted dipoles arrayed in the vertical dimension. The array weights were fixed and optimized for enhancing the antenna gain in the desired elevation coverage sector. More recently, the inclusion of MIMO techniques for capacity improvement in cellular standards, required the use of two or more of these *traditional* base station antennas. In particular, it has been shown that a good solution for multi-user MIMO is to array several of these antennas in the horizontal dimension using a distance between antennas of half-wavelength. In this case, the vertical beamforming weights (i.e. for each element inside each *traditional* antenna) remain fixed for optimized coverage whereas the horizontal beamforming weights (i.e. for each traditional antenna) are calculated in order to simultaneously form different azimuth beams towards the different users, resulting in a net capacity increase. For further capacity enhancement, Full-dimension MIMO (FD-MIMO) has been recently proposed [1]. Its main principal is the substitution of the *traditional* antennas by active antenna arrays capable of performing adaptive beamforming also in the elevation dimension. In other words, the overall antenna becomes a planar 2-D array in which the beamforming weight of each dual-polarized dipole element can be independently adjusted in order to discriminate users not only in the azimuth but also in the elevation dimension.

Several works demonstrated the improved throughput achieved by FD-MIMO arrays in comparison with only azimuth beamforming solutions [1-3]. A major finding of [1] is that the system throughput can be increased by using inter-element distances of 2λ (half-wavelengths) between vertical antennas instead of the usual λ/2. The reason for this is the reduced beamwidth obtained by the larger aperture. However, [1] does not give any physical insight behind the 2λ value nor evaluates the impact of the grating lobes resulting from the large inter-element spacing.

Therefore, the main purpose of this paper is to evaluate the tradeoff between the reduced beamwidth and the generation of grating lobes when using FD-MIMO arrays with inter-element distances greater than λ/2.

II. REVIEW OF ARRAY FACTOR BEAMWIDTH AND GRATING LOBES

The array factor half-power bandwidth of a uniform linear array pointing at broadside can be approximated by [4]

$$HPBW \cong 2\left[\frac{\pi}{2} - cos^{-1}\left(\frac{1.391\lambda}{\pi N d}\right)\right] \quad (1)$$

where λ is the wavelength, N is the number of antennas and d is the distance between antennas. It is easy to see that as d increases the second term in (1) tends to π/2 so the HPBW is reduced. This result can be generalized to arrays pointing to any direction. From (1), it can be concluded that increasing d above λ/2 allows reducing the interference to close users without the need of increasing the number of antennas, as already proposed in [1]. However, in order to rule out all grating lobes the inter-element distance must also fulfill

$$\frac{d}{\lambda} < \frac{1}{1+cos\theta} \quad (2)$$

where θ is the direction towards which the array is pointing. If the array has to cover the entire half-space, $d< \lambda/2$ is required in order to avoid grating lobes that could interfere other users. Therefore, there is a clear tradeoff between the beamwidth reduction and the appearance of grating lobes which is evaluated in the following sections. The directions of the grating lobes can be calculated as follows

$$\theta_{GL} = cos^{-1}\left(\pm\frac{m}{d} + cos(\theta)\right) \quad (3)$$

where θ is the direction towards which the array is pointing.

III. FD-MIMO IN LINE-OF-SIGHT CONDITIONS

The tradeoff between beamwidth and grating lobes in FD-MIMO arrays with inter-element spacings larger than half-wavelength is assessed here by independently analyzing the azimuth and elevation dimensions. For this, linear arrays with isotropic and uncoupled elements in ideal line-of-sight (LOS) conditions are evaluated. The scenario considered is a downlink communication in a single 120º sector of a 500m diameter cell. In this scenario, a base station (BS) with 16 antennas simultaneously serves 4 users uniformly distributed inside this sector, but keeping a minimum distance from the BS of 50m in order to fulfil the assumptions of the channel model that will be used in next section. In this conditions, the corresponding channel matrix is formed by the steering vectors of each user stacked in different rows. The simplest precoding scheme based on maximum ratio transmission (MRT) [2] and a SNR=20dB are considered. For analyzing the elevation dimension, vertical arrays placed at different heights are evaluated in order to study the relationship between the inter-element distance and the size of the elevation angular sector. The relationship between array height and angular sector is summarized in table 1. For the azimuth dimension, a single horizontal array is used. Figure 1 shows the simulated sector sumrate for each array configuration, calculated as in [2] and averaged over 1000 Montecarlo realizations.

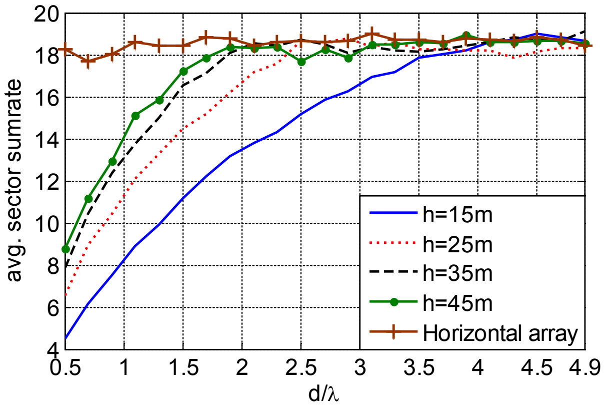

Fig. 1. Average sector sumrate versus inter-element spacing in LOS scenarios

TABLE I. ANGULAR SECTOR VS BASE STATION HEIGHT

BS height (m)	**Angular sector size (º)**	**Minimum antenna spacing creating grating lobes inside the sector of interest. (λ)**
15	13	4.4
25	21	2.9
35	27	2.3
45	32	2.1
Horizontal array	120	0.6

It can be observed that, regardless of the base station height; hence regardless of the size of the angular sector, all array solutions converge to the same saturated sumrate when enough inter-element spacing is used. Moreover, as *a priori* expected, lower angular sectors require longer antenna spacings for reaching the saturation regime. However, Table 1 and Figure 1 also show that for each array height, the saturated sumrate is obtained when the spacing between antennas is large enough so that the grating lobes start falling inside the sector of interest. The minimum antenna spacing creating grating lobes inside the sector of interest in Table 1 is manually calculated using (3) and setting the pointing direction to the limit of the desired sector . In the saturation regime, the benefits of the reduced beamwidths are cancelled out by the appearance of grating lobes inside the sector. Therefore, the optimum antenna spacing appears to be the one that makes the grating lobes start appearing inside the desired sector. It is also remarkable, that a spacing of half-wavelength is already close to be optimum in the case of horizontal arrays due to the large azimuth sector.

IV. FD-MIMO IN 3D-URBAN MACRO SCENARIOS

For a more realistic assessment of the impact of different antenna spacings, the 3D spatial channel model (3D-SCM) used in [2] and based on WINNER+ project is utilized. In this case, the BS height is set to 25m, and the linear arrays of 16 antenna elements are formed by 8 pairs of 45º slanted cross-dipoles backed by a perfect conductor. The polarization of users is assumed to be random and LOS and NLOS conditions are set according to the probabilities defined in the WINNER+ model. Pathloss and shadowing effects are not taken in account and a uniform power allocation among users is assumed.

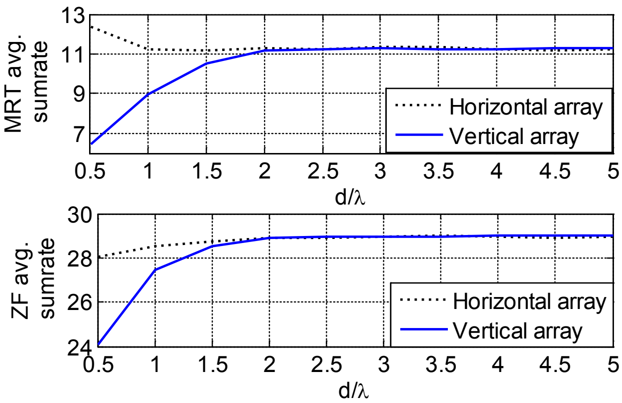

Fig. 2. Average sector sumrate versus inter-element spacing using a realist 3D-SCm channel model

Simulations results are plotted in Figure 2 for two different precoding schemes; the zero forcing (ZF) and the MRT. The results are qualitatively analogous to the ones obtained in ideal LOS conditions, but lower spacings are needed to reach the saturation regime due to the beneficial decorrelating effect of the channel. For the vertical arrays, both ZF and MRT lead to the same optimum antenna spacing, whereas for the horizontal arrays, the interference mitigation capabilities of the ZF allow obtaining small benefit using antenna spacing between λ and 1.5λ. Simulations revealed that FD arrays with λ/2 spacings in the horizontal dimension and an increasing spacing in the vertical one produce the same saturation point as linear vertical arrays, though the absolute sumrate achieved is lower for the linear case. In conclusion, for reduced elevation sectors, increasing the vertical distance between antenna elements provides a sumrate increase until a saturation point is reached. Beyond this point, the grating lobes cancel out the benefits of reduced beamwidths.

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