Impact of User Spread on the Input Power Spread in DL Massive MIMO in Random LOS Channels

Andrés Alayón Glazunov[1,2] and Yang Miao[1]
[1]Department of Electrical Engineering, University of Twente, Enschede, Netherlands
[2]Department of Electrical Engineering, Chalmers University of Technology, Gothenburg, Sweden

***Abstract*—Presented are the spread of the amplifier output power and the sum rate capacity loss of a narrowband massive MIMO antenna system in a Random-LOS channel due to cell-sector narrowing. Coupling effects between the array elements have been neglected. A large power spread of the output power of the amplifiers is observed when users are spread over narrow sectors and ZF-precoding is used. The capacity is considerably reduced for both MF- and ZF-precoding, especially for the latter.**

I. Introduction

In Massive Multi-User Multiple-Input Multiple-Output (MIMO) technology a base station (BS) is equipped with an array antenna with a large number of antenna elements and it serves many users in the same time-frequency resource. In so-called favorable propagation (FP) conditions linear processing becomes nearly optimal [1]. The Random Line-Of-Sight (Random-LOS) propagation channel represent a limiting propagation channel, where the angular spread of scatterers around the user equipment is non-existent. It has been argued that this type of channel provides FP conditions [2], [3]. Narrowing the cell-sector size is traditionally used to increase system capacity, in which case the angular spread of uniformly distributed users over the sector reduces. In this paper we investigate the impact of the sectoring characterized by the user spread angle ψ on the output power of the amplifier and the capacity loss in the downlink for the classical Zero-Forcing (ZF) and the Matched-Filtering (MF) precoding schemes.

II. System Model and Figures of Merit

K single-antenna users are served by a base station (BS) equipped with M antenna elements where $M \geq K$. The power of the signal vector transmitted from the BS antenna array is normalized to unity. The Random-LOS channel is considered [4], where randomness is assumed to stem only from users' positions that are uniformly distributed over the coverage area. Far-field conditions are assumed between a user antenna and a transmit antenna element of the massive uniform linear array. The coupling between the two antennas defines an entry of the channel matrix with unit power normalization. For details on the system and channel models see, e.g., [4]. Different cell-sector angles, i.e., user spread angles $\psi \in \{1°, 120°\}$ are considered. Perfect Channel State Information (CSI) is assumed at both the receiver and the transmitter. We consider the Zero-Forcing (ZF) precoding and the Matched-Filtering(MF) linear precoding schemes.

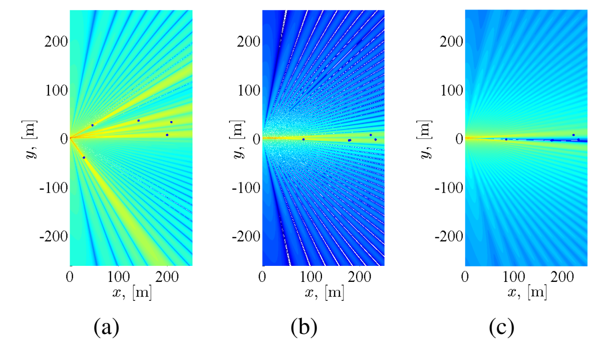


Fig. 1. Spatial distribution of the power radiated by a Massive MIMO systems (ULA with $M = 50$ antenna elements) in the downlink towards $K = 5$ users in pure LOS. (a) Wide-angle user spread $\psi = 120°$ with MF-precoding, (b) Narrow-angle user spread $\psi = 4°$ with MF-precoding and (c) Narrow-angle user spread $\psi = 4°$ with ZF-precoding.

We consider two figures of merit: the ergodic sum rate capacity of the $(M \times K)$ Massive MIMO system [4], and the power spread parameter quantifying the fluctuations of the power amplifier (PA) output power levels. The power spread is defined as

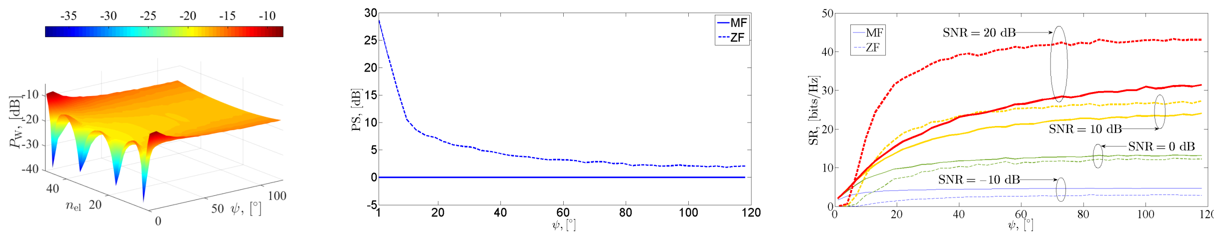
$$\mathrm{PS}(\psi) = \frac{\max(\mathrm{MEAN}\{P_{\mathrm{W,tot}}\} + \mathrm{VAR}\{P_{\mathrm{W,tot}}\})}{\min(\mathrm{MEAN}\{P_{\mathrm{W,tot}}\} - \mathrm{VAR}\{P_{\mathrm{W,tot}}\})}, \quad (1)$$

where the max and min is taken over the antenna elements $P_{\mathrm{W,tot}}$ is a vector containing the output powers of each of the PAs at the different channel realizations for different user spread angle ψ. The operators $\mathrm{MEAN}\{P_{\mathrm{W,tot}}\}$ and $\mathrm{VAR}\{P_{\mathrm{W,tot}}\}$ compute the mean and variance over the channel realizations. In the ideal case $\mathrm{PS}(\psi) = 1$ in 0 dB-scale.

III. Simulation results

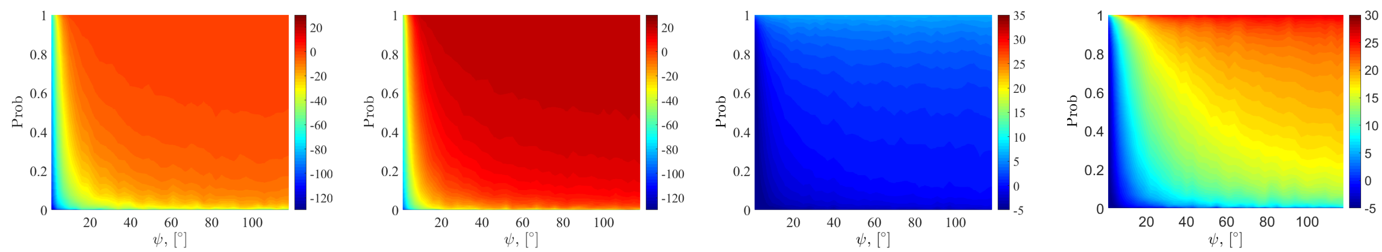
We assume $f = 30$ GHz, an array of $M = 50$ isotropic elements separated at the distance $d = \lambda/2 = 0.005$ m. Hence, the size of the array can be computed as $L = M\lambda/2 = 0.25$ m. The $K = 5$ users are uniformly distributed over a single circular sector-cell between 12.5 m and 250 m from the BS and a width of $\psi \in \{1°, 120°\}$, which also defines the user spread within the cell. Each user is equipped with an isotropic antenna. Vertical polarization is assumed. Examples illustrating 5 users in a sector with wide ($\psi = 120°$) and narrow ($\psi = 4°$) user angle spread are shown in Fig.1.

Fig.2(a) shows that the ZF-precoding PA output power fluctuations increase across different antenna elements with



(a) (b) (c)

Fig. 2. (a) Average PA power output at each antenna element of the Massive MIMO antenna as function of the antenna element number n_{el} and the user spread angle ψ for ZF-precoding, (b) PS of MF- and ZF-precoding as a function of ψ, (c) Sum rate capacity SR of MF- and ZF-precoding in Random-LOS as a function of ψ. Results are presented for four average per-user SNR values: -10, 0, 10 and 20 dB. $M = 50$ and $K = 5$.



(a) (b) (c) (d)

Fig. 3. Contour plot of the SINR obtained as a function the cumulative probability level Prob and user spread angle ψ with ZF-precoding when (a) $SNR = -10$ dB, and (b) $SNR = 10$. $M = 50$ and $K = 5$ and with MF-precoding when (c) $SNR = -10$ dB, and (d) $SNR = 10$. $M = 50$ and $K = 5$.

number n_{el} as the user spread angle ψ reduces. The fluctuations are compactly illustrated in Fig.2(b), where the power spread PS (1) is presented as a function of the user spread angle ψ. Clearly, for $\psi \leq 60°$ the PA output power experiences much larger fluctuations than for wider sectoring. However, solid state PAs work at a fixed maximum output power with most efficient operation at saturation [5]. Hence, a larger PS due to sectoring sets harder requirements on the PA performance. For the MF-precoding, the output power of the PAs doesn't change under these idealized conditions. Omitted here due to lack of space. Fig.2(c) shows a considerable sum rate capacity loss for the MF-precoding as function of ψ. However, the capacity loss for ZF-precoding is even higher as the user spread angle decreases. This can be explained by the fact that the ZF-precoding puts a null towards the interfering signal. However, at low angular separation between users, they become indistinguishable for the ZF-precoder and are all nullified. On the other hand, since the MF-precoder maximizes power towards the intended user and the SINR is not null. This behaviour becomes clear by comparing Figs.3(a) and (b) depicting the contour plots of the SINR distribution obtained as a function the cumulative probability level Prob and ψ with MF-precoding, for low and high SNRs, respectively. Corresponding results for the ZF-precoding are shown in Fig.3(c) and (d). As can be seen the capacity loss for smaller user spread is larger at larger SNRs. An analysis of improvements obtained by means of sparse arrays with the inter-element spacings larger than 0.5λ leading to a reduction of the power variation along the array are discussed in [4], [6]. In [4], an upper bound for the inter-element spacing that deepends on the corresponding FoV (or user spread angle as we refer to it here), has been derived to prevent ZF-precoding singularity problems due to grating lobes for the 2-user case.

IV. Conclusions

We have shown that sectoring has a larger impact on the Massive MIMO ZF-precoding which shows both a larger PA output power spread and capacity loss as the user spread angle decreases as compared to MF-precoding under similar conditions.

Acknowledgement

The financial support by the EU is3DMIMO project with grant agreement number 734798-H2020-MSCA-RISE-2017 is kindly acknowledged.

References

[1] F. Rusek, et.al., "Scaling up MIMO: Opportunities and challenges with very large arrays," *IEEE Signal Process. Mag.*, vol. 30, no. 1, pp. 40–46, Jan. 2013.

[2] H. Q. Ngo, E. G. Larsson, and T. L. Marzetta, "Aspects of favorable propagation in massive MIMO," *in Proc. EUSIPCO*, 2014.

[3] E. Björnson, E. G. Larsson, and T. L. Marzetta, "Massive MIMO: 10 myths and one grand question," *arXiv preprint* arXiv:1503.06854, Mar. 2015.

[4] N. Amani, et.al., "Per-antenna power distribution of a zero-forcing beamformed ula in pure los mumimo," IEEE Com. Letters, 2018.

[5] D. Persson, T. Eriksson, and E. G. Larsson, "Amplifier-aware multiple-input single-output capacity," IEEE Trans. Commun., vol. 62, no. 3, pp. 913–919, Mar 2014.

[6] C. Bencivenni, et.al.,"Effects of Regular and Aperiodic Array Layout in Multi-User MIMO," arXiv:1808.08321 [eess.SP].

[7] A. A. Glazunov, "Impact of deficient array antenna elements on downlink massive MIMO performance in RIMP and random-LOS channels," *in Proc. 12th EuCAP*, London, 2018, pp. 1-4.

[8] A. A. Glazunov, "Downlink Massive MIMO performance of a vertically polarized uniform linear array in Random Line-Of-Sight," *in Proc. 10th EuCAP*, Davos, 2016, pp. 1-4.