User Grouping for Non-Coherent DPSK Massive SIMO with Heterogeneous Propagation Conditions

Victor Monzon Baeza and Ana Garcia Armada

University Carlos III of Madrid, Leganes (Madrid), Spain
e-mail: `vmonzon@tsc.uc3m.es`, `agarcia@tsc.uc3m.es`

Abstract—**In this paper we analyze a multi-user non-coherent massive single input multiple output (m-SIMO) uplink system based on M-DPSK in heterogeneous scenarios, where both Rayleigh and Rician fading are present. The performance analysis shows that grouping users with different fading in the same physical resource has advantages in terms of constellation design and receiver complexity.**

Index Terms—**Massive MIMO, non-coherent detection, 5G.**

I. INTRODUCTION

The new standards for future communications systems, such as fifth Generation (5G) and beyond, are considering the massive multiple input-multiple output (m-MIMO) schemes because of their great spectral- and energy-efficiency. M-MIMO increases enormously the number of antennas in the base stations (BS), thus rising issues in the acquisition of the Channel State Information (CSI) when we make a coherent detection. This drawback seriously compromises the performance of these systems in new scenarios emerging with 5G [1].

The non coherent detection is an alternative solution to circumvent the difficulty in estimating large amounts of CSI. Most research has been focused on the constellation design to multiplex and non coherently detect several users. The designs based on Differential Phase Shift Keying (DPSK) [2], [3] have shown a better performance against the ones based on energy detection [4], [5]. Channel coding schemes are introduced in both designs to reduce the number of antennas for practical systems. However, [4] still employs an impractical number of antennas. Therefore, in this work we focus on DPSK schemes.

On the other hand, the previous works have been analyzed for a channel propagation model with either Rayleigh fading or Rician fading. However, in order to increase the capacity of the system, we can multiplex users with different channel fading in the same physical resource. Thus, we obtain heterogeneous scenarios in terms of propagation characteristics. Hence, in this work we study the effect on the performance and the complexity of the system when both fading types are present.

The new 5G introduces some emerging scenarios such as device to device communications or wireless self-backhauling [6] where the Line of Sight (LOS) channel component may be predominant and modeled with Rician fading. This component causes an interfering term in non coherent (NC) DPSK systems which has to be detected and cancelled. To do that effectively, the receiver has to assume certain complexity. Only if this term is compensated, the performance obtained under purely Rice fading will be better than with Rayleigh fading. Otherwise, the users may not be error-free detected in a non-coherent m-MIMO based on DPSK with pure Rician channels. In [7], an algorithm was proposed to detect and correct the interfering term due to the LOS component. For that purpose, the constellation was redesigned. so that one should choose a different constellation for the transmission depending on the expected propagation environment. However, this design was only valid for two users and short frames of symbols due to the high complexity regarding the number of operations at the receiver side which the algorithm requires.

The scheduling of users which experience a pure Rayleigh fading combined with the ones with a pure Rice channel can help to improve the performance and reduce the complexity compared to the scenarios with only Rician fading. The novel contribution of this work is the analysis of the signal to interference plus noise ratio (SINR) and the performance in terms of symbol error rate (SER) of NC DPSK-based massive SIMO in heterogeneous scenarios with Rayleigh and Rice fading. We also quantify the advantage of the mixed-propagation user grouping in terms of complexity.

The rest of the paper is organized as follows. In Section II the system model is presented. In Section III the derivation of SINR is shown. The performance is analyzed in Section IV. Finally, Section V presents our conclusions and future work.

II. SYSTEM MODEL

In this work, we consider a multi-user single input multiple output (SIMO) uplink scenario, where a single base station (BS) is equipped with R receive antennas (RA) to receive the signals transmitted from J users. The signals transmitted from J_1 of them experience Rayleigh fading (we refer to that circumstance in the following as the Rayleigh case), while the signals transmitted from the other $J_2 = J - J_1$ follow a Rician fading (Rician case) as shown in Fig. 1.

We denote the signal to be transmitted by user j at time instant n as $x_j[n]$. The signals from all users are grouped into the $(J \times 1)$-element vector $\boldsymbol{x}$. Each of the user signals are a differentially encoded version of $s_j[n]$ formulated as

$$x_j[n] = x_j[n-1]s_j[n] \tag{1}$$

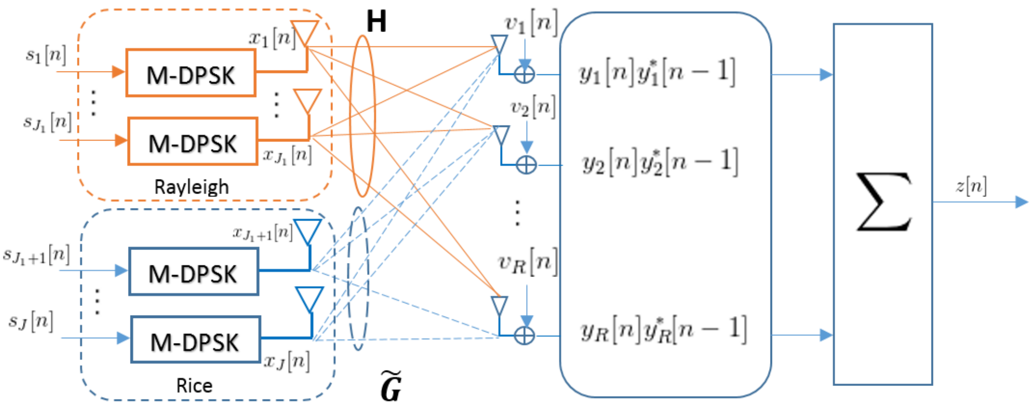

Fig. 1. System Model for Non Coherent Multi-user Massive SIMO system for L users

The symbols $s_j[n]$ belong to the M-PSK constellation designed in [2] defined as

$$\mathfrak{M}_j = \left\{ \frac{2\pi[(m+1)J-1+j]}{JM}, m=0,1,...,M-1 \right\}, \tag{2}$$

where $|s_{m,j}[n]| = 1$ and M is the order of the constellation. For a pure Rice channel, the constellation had to be redesigned in [7] due to the LOS component. This constellation is also based on an M-PSK scheme where there are restrictions on the symmetry of the constellation points. In this work, we will demonstrate that the design (2) will be also valid for Rician fading when we combine users with both types of fading (Rayleigh and Rician) in the same physical (time, frequency) resource. The $x_j[0]$ is a first symbol known at the transmitter and receiver which is taken from the constellation $\mathfrak{M}_j$.

The m-MIMO wireless channel is modeled on one hand by the $(R \times J_1)$-element matrix $\boldsymbol{H}$, whose elements $h_{rj} \sim CN(0,1)$ represent the propagation between user j and the r-th antenna at the BS for the user group whose signals experience a Rayleigh fading. On the other hand, for the case of the user group whose signals follow a Rician fading, the channel is modeled by a matrix $\widetilde{\boldsymbol{G}} = \boldsymbol{G} + \mu$ of size $(R \times J_2)$. Its elements $\widetilde{g}_{rj} = g_{rj} + \mu$, where $g_{rj} \sim CN(0, \sigma_g^2)$, are circularly symmetric complex Gaussian random variables. Hence, we have extracted the mean of the channel μ to remark the effect of the LOS channel component. We assume that the parameters of the channel for the Rician case are defined as follows

$$\mu^2 = \frac{K}{K+1} \quad and \quad \sigma_g^2 = \frac{1}{K+1}, \tag{3}$$

where K is the Rician factor ($K > 0$) [8]. For simplicity of the presentation, we assume that all the channels that experience Rician fading have the same K-factor. The $(R \times 1)$-element vector $\boldsymbol{y}[n]$ groups the signals received in each of the BS antennas at time instant n. Then, $\boldsymbol{y}[n]$ is obtained as follows[1]

$$\boldsymbol{y} = [\boldsymbol{H} \ \widetilde{\boldsymbol{G}}]\boldsymbol{x} + \boldsymbol{\nu}. \tag{4}$$

Here the AWGN is represented by the $(R \times 1)$-element vector $\boldsymbol{\nu}$, $\nu_r[n] \sim CN(0, \sigma^2)$. The power of the signal received at each antenna is

$$E\left\{ \left\| [\boldsymbol{H} \ \widetilde{\boldsymbol{G}}]\boldsymbol{x} \right\|^2 \right\} = \sum_{j=1}^{J_1} |s_j|^2 + \sum_{j=J_1+1}^{J} |s_j|^2 (\sigma_g^2 + \mu^2) = J, \tag{5}$$

as $|s_j|^2 = 1$ and $(\sigma_g^2 + \mu^2) = 1$. We define the reference SNR as

$$\rho = \frac{E\left\{ \left\| [\boldsymbol{H} \ \widetilde{\boldsymbol{G}}]\boldsymbol{x} \right\|^2 \right\}}{\sigma^2} = \frac{J}{\sigma^2}. \tag{6}$$

At the receiver shown in Fig. 1, we assume that $h_{rj}[n-1] = h_{rj}[n] = h_{rj}$, $r = 1,...,R$ and $j = 1,...,J_1$, meaning that the channel stays time-invariant for two consecutive symbols[2] . In the same way $g_{rj}[n-1] = g_{rj}[n] = g_{rj}$, $r = 1,...,R$ and $j = J_1+1,...,J$. Hence, the phase difference is non-coherently detected for these two symbols received at each antenna. The resulting received symbol is the decision variable $z[n]$ defined as follows

$$z[n] = \frac{1}{R} \sum_{r=1}^{R} y_r[n-1]^* y_r[n], \tag{7}$$

that contains information and interference gleaned from all antennas. Using the Law of Large Numbers [10] we may examine the different terms of interference in (8) as follows

$$\begin{aligned} &\text{Rayleigh case: } j = 1,...,J_1 \rightarrow \tfrac{1}{R}\textstyle\sum_{r=1}^{R} |h_{rj}|^2 \overset{R\to\infty}{=} 1, \\ &\text{Rician case: } j = J_1+1,...,J \rightarrow \tfrac{1}{R}\textstyle\sum_{r=1}^{R} |g_{rj}|^2 \overset{R\to\infty}{=} \sigma_g^2, \end{aligned} \tag{9}$$

$$\frac{1}{R} \sum_{r=1}^{R} \sum_{j=1}^{J_1} \sum_{\substack{k=1 \\ k \neq j}}^{J_1} \mu h_{rj} x_j[n] x*_k[n-1] \overset{R\to\infty}{=} 0, \tag{10}$$

$$\frac{\mu}{R} [\sum_{r=1}^{R} x_j^*[n-1] v_r[n] + \sum_{r=1}^{R} x_j[n] v_r^*[n-1]] \overset{R\to\infty}{=} 0, \tag{11}$$

---

[1] We will remove the time dependency with n to facilitate the notation.

[2] In a real scenario there will be a small variation between these two channels, this is just an assumption for the analysis. It is shown in [9] that our scheme is very robust to the channel variability that is likely to happen in realistic scenarios.

$$
\begin{aligned}
i[n] = z[n] - \varsigma[n] = {} & \underbrace{\frac{1}{R}\sum_{r=1}^{R}\sum_{j=1}^{J_1}|h_{rj}|^2 s_j[n] + \frac{1}{R}\sum_{r=1}^{R}\sum_{j=J_1+1}^{J}[|g_{rj}|^2 + 2\mu\Re\{g_{rj}\} + \mu^2]s_j[n] - \sum_{j=1}^{J_1} s_j[n] - \sum_{j=J_1+1}^{J} s_j[n]}_{i_0[n]} \\
& \underbrace{+\frac{1}{R}\sum_{r=1}^{R}\left[\sum_{j=1}^{J_1}\left(\sum_{\substack{k=1\\k\neq j}}^{J_1} h_{rj}h_{rk}^{*}x_j[n]x_k^{*}[n-1] + h_{rj}x_j[n]v_r^{*}[n-1] + h_{rj}^{*}x_j^{*}[n-1]v_r[n]\right)\right]}_{i_{rayleigh}[n] \quad due\ to\ Rayleigh\ fading} \\
& \underbrace{+\frac{\mu}{R}\sum_{r=1}^{R}\left[\sum_{j=J_1+1}^{J} x_j[n]v_r^{*}[n-1] + \sum_{j=J_1+1}^{J} x_j^{*}[n-1]v_r[n]\right]}_{i_{rice}[n],\quad due\ to\ Rician\ fading} + \underbrace{\frac{1}{R}\sum_{r=1}^{R} v_r[n]v_r^{*}[n-1]}_{i_{noise}[n],\quad noise\ terms} \qquad (8) \\
& \underbrace{+\frac{1}{R}\sum_{r=1}^{R}\sum_{j=J_1+1}^{J}\sum_{\substack{k=1\\k\neq j}}^{J}\left(g_{rj}g_{rk}^{*}x_j[n]x_k^{*}[n-1] + g_{rj}x_j[n]v_r^{*}[n-1] + g_{rj}^{*}x_j^{*}[n-1]v_r[n] + \mu g_{rj}x_j[n]x_k^{*}[n-1] + \mu g_{rj}^{*}x_j^{*}[n-1]x_k[n]\right)}_{i_{rice}[n],\quad due\ to\ Rician\ fading} \\
& \underbrace{+\frac{\mu}{R}\sum_{r=1}^{R}\sum_{j=1}^{J_1}\sum_{j=J_1+1}^{J}\left[h_{rj}x_j[n]x_j^{*}[n-1] + h_{rj}^{*}x_j^{*}[n-1]x_j[n] + h_{rj}g_{rj}^{*}x_j[n]x_j^{*}[n-1] + h_{rj}^{*}g_{rj}x_j^{*}[n-1]x_j[n]\right]}_{i_{mixture}[n],\quad terms\ due\ to\ the\ mixture\ of\ fading\ types}
\end{aligned}
$$

and the new terms due to the mixture of both types of channel fading obey

$$
\frac{\mu}{R}\sum_{r=1}^{R}\sum_{j=1}^{J_1}\sum_{p=J_1+1}^{J}\left[h_{rj}x_j[n]x_p^{*}[n-1] + h_{rj}^{*}x_j^{*}[n-1]x_p[n]\right] \overset{R\to\infty}{=} 0, \tag{12}
$$

$$
\frac{1}{R}\sum_{r=1}^{R}\sum_{j=1}^{J_1}\sum_{p=J_1+1}^{J}\left[h_{rj}g_{rp}^{*}x_j[n]x_p^{*}[n-1]+\right] \overset{R\to\infty}{=} 0. \tag{13}
$$

We define the joint symbol at the receiver side as

$$
\varsigma[n] = \sum_{j=1}^{J} s_j[n], \tag{14}
$$

then as R grows bigger, (7) can be approximated as

$$
z[n] \overset{R\to\infty}{=} \varsigma[n] + i[n] \tag{15}
$$

and making a minimum distance detection with the joint symbol as it was shown in [2] and [7], we retrieve the user symbols $s_j[n]$.

III. ANALYSIS OF THE SIGNAL TO INTERFERENCE PLUS NOISE RATIO

The Signal to Interference plus Noise Ratio (SINR) is defined as the ratio of the signal power to the power of AWGN noise plus interference. When detecting ς from $z[n]$, the interference plus noise arise from the interfering terms $i[n]$ in (15). We group these terms in interference caused by Rayleigh fading, the interference caused by the Rician fading and the terms which appear due to AWGN noise. We use the SINR for pure Rayleigh and pure Rician fading defined in [2] and [7] respectively as a reference to compare with the mixed mode. We define the following

$$
I_{Rayleigh}^{0} = \frac{J_1^2}{R} \quad and \quad I_{Rice}^{0} = \frac{J_2^2\sigma_g^2\mu}{R} \tag{16}
$$

$$
I_{Rayleigh} = \frac{J_1(1+2\sigma^2)}{R} \tag{17}
$$

$$
I_{Rice} = \frac{(\sigma_g^4 + 2\sigma_g^2\sigma^2 + 2\mu^2(J_2-2)\sigma_g^2 + 2\mu^2\sigma^2)(J_2-1)}{R} \tag{18}
$$

$$
I_{noise} = \frac{\sigma^4}{R}. \tag{19}
$$

The new interfering terms due to the combined fading are obtained as $E\{|i_{mixture}[n]|^2\}$ resulting in

$$
I_{mixture} = \frac{2\mu^2 + 2\sigma_g^2}{R} \tag{20}
$$

and because of the mixture of fading types the first term also changes to $I^0 = I_{Rayleigh}^{0} + I_{Rice}^{0}$. Then the total SINR for a heterogeneous scenario obeys (21).

In Fig. 2 it is shown that (21) matches with the simulations for $R = 100$ antennas. The reference “pure” SINR is obtained for $J_1 = 2$ users experiencing both Rayleigh fading as [2] or $J_2 = 2$ users experiencing both Rician fading ($K = 5$) as [7]. We compare these SINR curves to (21) for a scenario where the same number of total users that experience different fading (Rayleigh and Rician) are scheduled together ($J_1 = J_2 = 1$). We can see that the new SINR when we combine users improves and that the SINR for the mixture is very close to the Rayleigh SINR. The curve for ideal pure Rice is a bound which can only

$$SINR=\frac{RJ}{\sigma_g^4+\sigma^4+\sigma^2(2J_1+2\sigma_g^2J_2+2\mu^2J_2)+\sigma_g^2(J_2^2\mu+2\mu^2J_2(J_2-1)+1J_1J_2)+J_1(2\mu^2J_2+J_1+1)} \tag{21}$$

be obtained when the LOS component is perfectly estimated. Grouping together users with different type of fading we get closer to this bound without the need for any complex detection algorithm in the receiver.

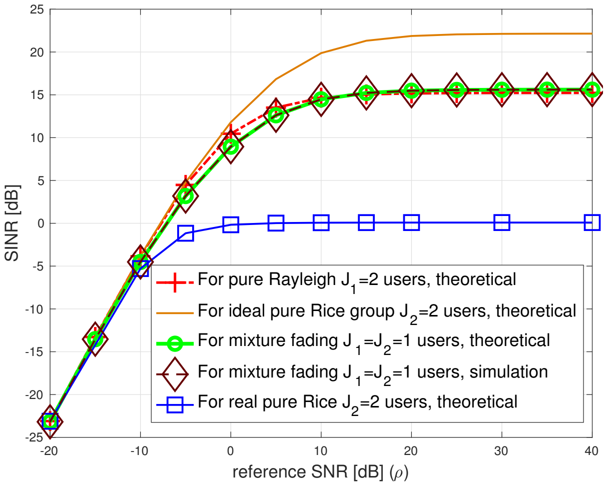

Fig. 2. Comparison of the SINR for pure Rayleigh and Rice mode with a fading mixture with $R = 100$ antennas.

IV. PERFORMANCE EVALUATION

In this section we examine the performance of our NC-m-SIMO when users experiencing Rayleigh and Rician fading are scheduled together. For the simulations, a random channel is generated at each iteration (minimum 100,000 iterations) following the model explained in section II and it is kept constant for 1,000 symbols. In the case for Rice fading, they have the same $K = 5$ factor following equations (3). The propagation channels of all the different users are uncorrelated.

We compare in Fig. 3 a combined scenario with $J = 2$ users ($J_1 = J_2 = 1$), for $M = 4$ and ρ = 0 dB to pure Rayleigh ($J_1 = 2$) and pure Rice ($J_2 = 2$) cases. We can see how combining 2 users with different fading, the user with Rayleigh propagation does not experience any changes, while the performance of the Rician-faded user improves with respect to the case of being multiplexed with another Rician-faded user. In addition, the constellation used in the mixed mode for both users is the same, that was defined in (2), while for pure Rician propagation the one in [7] has to be used, which offers a worse performance. We use the number of comparisons that must be performed between each symbol with all possible transmitted symbols for the detection process as a measure of the computational complexity of the system. Then the complexity is reduced from $M^J(M^2+1)$ to M^J by this adequate user grouping. In addition, the user detection is performed symbol by symbol now, avoiding the delay caused when the detection is done per frame.

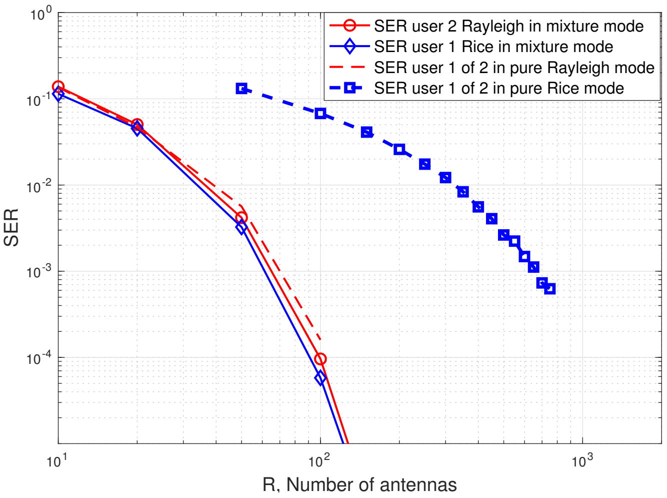

Fig. 3. SER for $\rho = 0$ dB, $J = 2$ users, $M = 4$, and $K = 5$.

In Fig. 4 the error performance is shown for $J = 4$ users with $M = 2$, $K = 5$ and $\rho = 0$dB where $J_1 = 3$ and $J_2 = 1$. The Rician-faced user also experiences the same performance as the other three ones that have Rayleigh propagation.

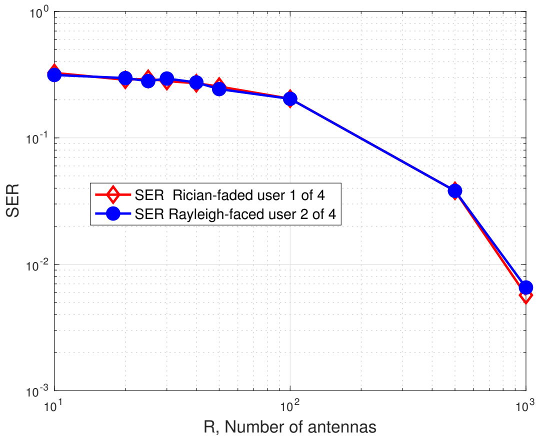

Fig. 4. SER for $\rho = 0$ dB, $J = 4$ users, $M = 4$, and $K = 5$.

V. CONCLUSIONS

We have proposed grouping users which experience a Rayleigh fading with those with Rician fading, analyzing the SINR and the performance of such combination in a multi-user NC m-SIMO system based on M-DPSK. The adequate user grouping allows unifying the constellation for both groups of users and the detection algorithm, reducing the complexity of the receiver. Also, the number of users that may be multiplexed may be further increased thanks to the improved performance.

ACKNOWLEDGMENT

This work has been partially funded by the Spanish National Project TERESA-ADA (TEC2017-90093-C3-2-R) (MINECO/AEI/FEDER, UE

REFERENCES

[1] E.G. Larsson, O. Edfors, F. Tufvesson, and T.L. Marzetta, "Massive MIMO for Next Generation Wireless Systems," *IEEE Comm. Mag.*, vol. 52, no. 2, pp. 186-195, Feb. 2014.

[2] V. M. Baeza, A. G. Armada, W. Zhang, M. El-Hajjar and L. Hanzo, "A Non-Coherent Multi-User Large Scale SIMO System Relying on M-ary DPSK and BICM-ID," *IEEE Trans. on Vehicular Technology*, vol. 67, pp.1809-1814, Feb. 2018.

[3] V.M. Baeza and A.G. Armada "Analysis of the Performance of a Non-Coherent Large Scale SIMO System Based on M-DPSK Under Rician Fading," *EUSIPCO*, vol. 1, pp-1-6, Kos Sep, 2017.

[4] M. Chowdhury, A. Manolakos and Andrea Goldsmith, "Scaling Laws for Noncoherent Energy-Based Communications in the SIMO MAC," *IEEE Transaction on Information Theory*, vol. 62, no. 4, Apr. 2016

[5] L. Jing, E. D. Carvalho, P. Popovski and A. O. Martínez, "Design and performance analysis of noncoherent detection systems with massive receiver arrays," *IEEE Trans. Signal Process.*, vol. 64, no. 19, pp. 5000-5010, Oct. 2016.

[6] H. Zhang, Y. Liao and Lingyang Song, "D2D-U: Device-to-Device Communications in Unlicensed Bands for 5G System," in *IEEE Trans. on Wireless Communications*, vol. 16, pp 3507-3519, Mar. 2017.

[7] V. Monzon Baeza and A. Garcia Armada "Non-Coherent Massive SIMO System based on M-DPSK for Rician Channels," in *IEEE Trans. on Vehicular Technology*, Jan. 2019.

[8] A. J. Goldsmith, "Wireless communications." Cambridge University Press, 2005.

[9] V.M. Baeza, A.G. Armada, M. El-Hajjar and L. Hanzo, "Performance of a Non-Coherent Massive SIMO M-DPSK System," *Vehicular Technology Conference*, Sep. 2017.

[10] A.M. Tulino, S. Verdu, "Random matrix theory and Wireless Communications," *Foundations and Trens in Communications and Information Theory*, vol. 1, No. 1, pp. 1-182, 2004.