COMPARISON OF MIMO ANTENNAS: PERFORMANCE MEASURES AND EVALUATION RESULTS OF TWO 2X2 ANTENNA CONFIGURATIONS

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ABSTRACT

In this paper, we examine the significance of antenna element properties on Multiple–Input Multiple–Output (MIMO) systems. We show that eigenvalue spread is not adequate quality factor for MIMO systems but total transferred power has also to be taken into account. Thus, we propose a novel performance measure for MIMO antenna systems called mean effective link gain (MELG), which is an extension of mean effective gain (MEG) for Single–Input Single–Output (SISO) systems. We also present an evaluation example of two MIMO antenna systems in two propagation environments.

I. INTRODUCTION

The Multiple–Input Multiple–Output (MIMO) concept has predicted to be an attractive solution to increase attainable capacity in wireless communication systems. Important requirement of functional MIMO system is the complex signal propagation channel, which can provide parallel sub–channels [1,2]. However, the capacity of MIMO system is not only subject to the complex propagation channel but also the type of the realistic antennas. The radiation pattern of an antenna is not uniform as a function of solid angle and a mobile station can be randomly oriented in azimuth and elevation planes. Thus, the used antenna elements and their orientation affect the achieved capacity of system, as it was shown e.g. in [3]. In this paper, we introduce the extension of the mean effective gain (MEG) for MIMO systems called the mean effective link gain (MELG), which evaluates the effect of the used antennas of MIMO system.

The paper is organized as follows. Two different normalization methods are discussed in Section II. The MELG is defined in Section III, and the evaluation examples of two MIMO antenna systems are given in Section IV. The work is concluded in Section V.

II. NORMALIZATION OF CAPACITY RESULTS

Consider a MIMO system with n_t transmit and n_r receive antennas. We have defined $\mathbf{R}^{(i)} = \mathbf{H}^{(i)}\mathbf{H}^{(i)H}$, where $\mathbf{H}^{(i)}$ is the realization of the channel. The instantaneous normalized channel capacity is given by

$$C_{\mathbf{H}}^{(i)} = \log_2\left|\mathbf{I} + \frac{\rho}{n_t}\mathbf{R}_{norm}^{(i)}\right|, \qquad (1)$$

where a slightly different notation from [1,2] is adopted. ρ is signal to noise ratio, and $\mathbf{I}$ is identity matrix. i indicates the outcome of the channel. Further, $\mathbf{R}_{norm}^{(i)}$ is denoted

$$\mathbf{R}_{norm}^{(i)} = \frac{\mathbf{H}^{(i)}\mathbf{H}^{(i)H}}{\frac{1}{n_t n_r} G_{norm}^{(i)}}, \qquad (2)$$

where

$$G_{norm}^{(i)} = \frac{1}{2N+1}\sum_{i-N}^{i+N}\left\|\mathbf{H}_{norm}^{(i)}\right\|_F^2 . \qquad (3)$$

$2N+1$ is the number of samples used in sliding mean, which is performed for fast fading averaging of $\mathbf{H}_{norm}^{(i)}$. $\|\bullet\|_F$ is Frobenius norm, and $(\bullet)^H$ is Hermitian transpose. In the ideal uncorrelated (iid) or correlated Rayleigh fading channels the sliding mean can be replaced by $E[\bullet]$, which is expectation over the outcomes of $\mathbf{H}_{norm}^{(i)}$. Thus the normalization of the results can be performed for the "antennas itself " by [2]

$$\mathbf{H}_{norm}^{(i)} = \mathbf{H}^{(i)} . \qquad (4)$$

However, in real channels, also the effect of used antennas is included in $\mathbf{H}^{(i)}$. If there is power unbalance between the received powers of the antennas caused by either the polarization mismatch of the antennas or the different radiation properties of the antennas − a typical situation especially at the mobile station side of the link − the normalization like in (4) does not predict the effect of used antennas correctly. In such a case we propose that the normalization of results should be performed using a reference antenna system by

$$\mathbf{H}_{norm}^{(i)} = \mathbf{H}_{ref}^{(i)} . \qquad (5)$$

Such normalization enables the fair comparison between investigated antennas.

III. GENERALIZATION OF MEG FOR MIMO SYSTEMS

The performance of an antenna can be estimated by means of the mean effective gain (MEG), which is defined as the power received by an antenna compared to some reference antenna [4]. The definition of the MEG is widely used since the evaluation of antenna elements of mobile terminal is important in the link level analysis of SISO and SIMO systems. A slightly modified expression from the original paper is given in [5] where the normalization is performed using isotropic sensors. Based on the fundamental work of [4,5], the extension of the MEG, which is called the mean effective link gain (MELG), is proposed for the evaluation of MIMO antenna prototypes. The instantaneous link gain is defined having the sum of link powers normalized by the link powers of isotropic antennas with the same number of elements according to

$$G_{link}^{(i)} = \frac{\left\|\mathbf{H}^{(i)}\right\|_F^2}{G_{norm}^{(i)}} . \qquad (6)$$

The mean effective link gain (MELG) is given by

$$MELG = \frac{1}{N_s}\sum_{i=1}^{N_s} G_{link}^{(i)} , \qquad (7)$$

where N_s is the number of samples over the investigated route. This expression can also be interpreted as the mean of the sum of the normalized eigenvalues.

IV. MEASUREMENT SET–UP AND EVALUATION RESULTS

Two 2×2 MIMO antenna systems were investigated to demonstrate the combined effect of the antenna and eigenvalue spread to the attained capacity of the system. The wideband channel sounder [6,7] was adopted in measuring two separate routes, a microcell (line of sight) and a small macrocell (non line of sight), both in Helsinki downtown. The measurement arrays – a zigzag antenna array at Tx, and a spherical antenna array at Rx – were equipped with dual–polarized patch antennas [6]. At Tx, two antennas from the adjacent elements of the measurement array were selected. At Rx, complex impulse responses – the outcomes of the measurement process – were post–processed using a beamforming algorithm delivering the directional information of the signal [6]. The beamforming algorithm implemented for the spherical antenna array enables full 3D–information about the incident signal. The post–processed signal was weighted with ideal half wavelength dipole antennas using procedure to be presented in [8]. Two 2×2 MIMO antenna configurations were adopted:

1) Two vertically polarized antennas and two vertically polarized dipoles at Tx and Rx, respectively (Co–polarized configuration).
2) Vertically and horizontally polarized antenna at Tx, and vertically and horizontally polarized dipole at Rx (Cross–polarized configuration).

The Rx dipole array was rotated in six positions by 30° steps to guarantee a statistically sufficient result. Inter–element spacing of the antennas was 0.5λ at both ends of the link. Normalization (5) was performed with two vertically polarized antennas and two isotropic sensors at Tx and Rx, respectively. The electric field of isotropic sensor is defined like

$$e = \sqrt{e_\theta^2 + e_\phi^2} = 1 , \qquad (8)$$

where e_θ and e_ϕ are the electric fields of vertically and horizontally polarized field components, respectively. Practically the isotropic sensor is defined like "invisible" antenna, which causes no response for the incoming signal estimation performed by beamforming. The length of the sliding window in (3) was 101 samples ($2N$+1 = 101). The total number of samples was 2500 (appr. 87m in length) in the microcell route and 1342 (appr. 47m in length) in the small macrocell route.

The MELG values (7) are presented in Table 1. The cdfs of instantaneous capacity results (1) are presented as a function of ρ in Fig. 1. The eigenvalues of $\mathbf{R}_{norm}^{(i)}$ (2) are illustrated in Fig. 2. The capacity curves of two MIMO antenna configurations cross at the SNR value of 15 dB in the microcell case (see Fig. 1a). The reason is that the MIMO configuration of the cross–polarized antennas yields a clearly narrower eigenvalue spread, which is beneficial in high SNR values (see Fig. 2 a), whereas the configuration of the co–polarized antennas has a higher MELG value (4.7 dB), which is dominant in low SNR values (see Table 1). In the small macrocell case the ergodic capacity is higher for the co–polarized antennas in whole range (see Fig. 1b). This is caused by the small difference between the eigenvalue spread results as compared to the microcell (see Fig. 2b) and, on the other hand, 4 dB difference in the MELG values. It is evident according to these results that a narrow eigenvalue spread of one MIMO antenna configuration does not necessarily guarantee a higher capacity as compared to the other system with higher MELG value.

The normalization by (4) instead of (5) would shift the eigenvalues of the cross–polarized system to the right, which actually removes the effect of MELG (see Table 2). In such a case the cross–polarized system seems to yield higher mean capacity in whole range. Figs. 3 and 4 present the results of using (4) in normalization. The respective MELG results are presented in Table 2.

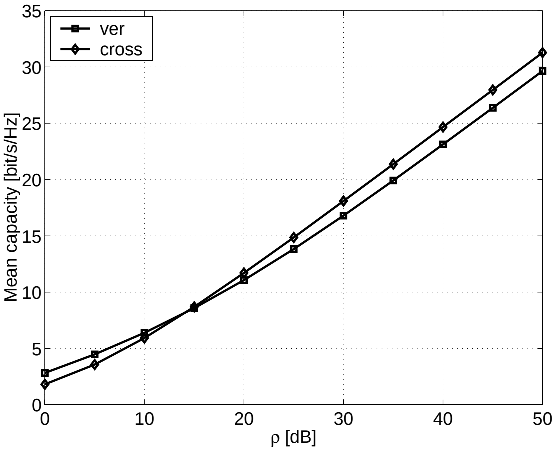
In summary, the normalization of (5) takes into account both the effect of eigenvalue spread and the effect of total transferred power of the antennas, whereas the normalization of (4) takes into account only the effect of eigenvalue spread. Because of that reason the former approach is more informative to evaluate MIMO antenna configurations.

Table 1. MELG results of the investigated antenna systems in two environments using (5) in normalization.

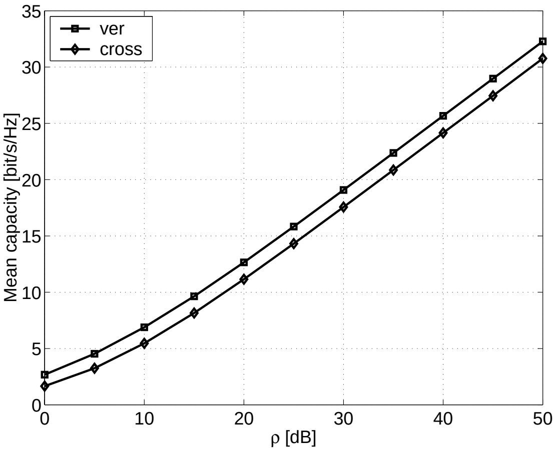
Ant.\Env.	microcell	small macrocell
Co–pol.	4.7 dB	4.1 dB
Cross–pol.	0.2 dB	0.1 dB

Table 2. MELG results of the investigated antenna systems in two environments using (4) in normalization.

Ant.\Env.	microcell	small macrocell
Co–pol.	2.9 dB	3.0 dB
Cross–pol.	2.9 dB	3.0 dB

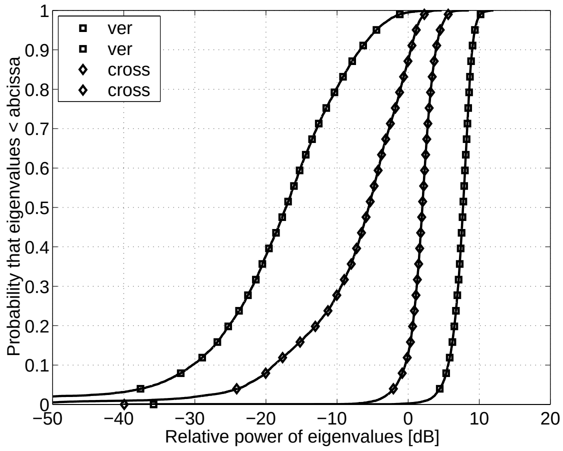


a)



b)

Fig. 1. Mean capacity of the investigated MIMO systems as a function of ρ. (5) used in normalization. a) microcell. b) small macrocell.



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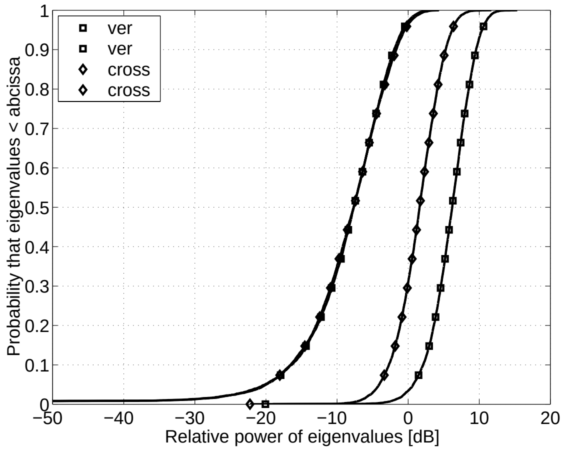

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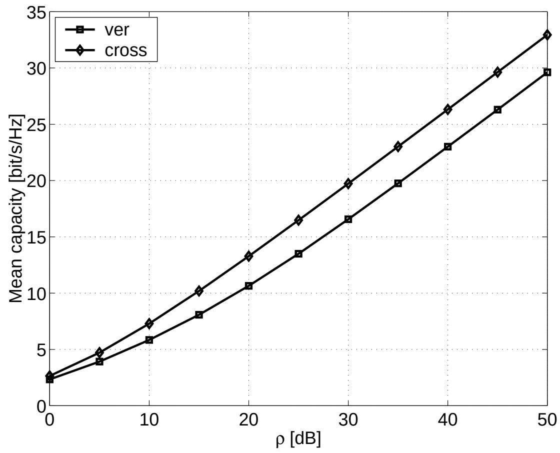
Fig. 2. Eigenvalues of the investigated MIMO systems. (5) used in normalization. a) microcell. b) small macrocell.



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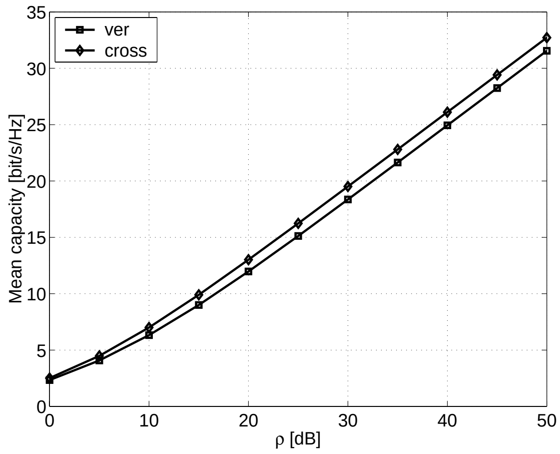
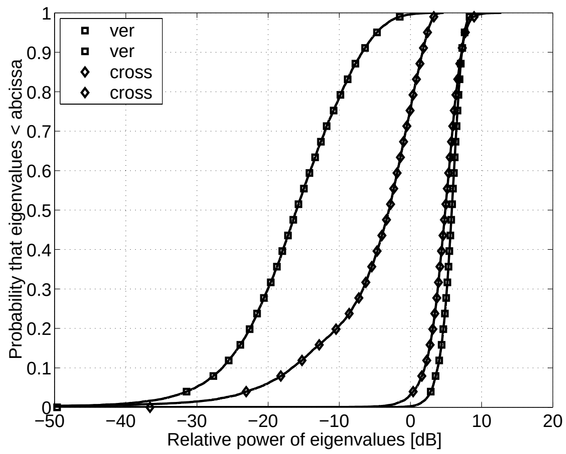
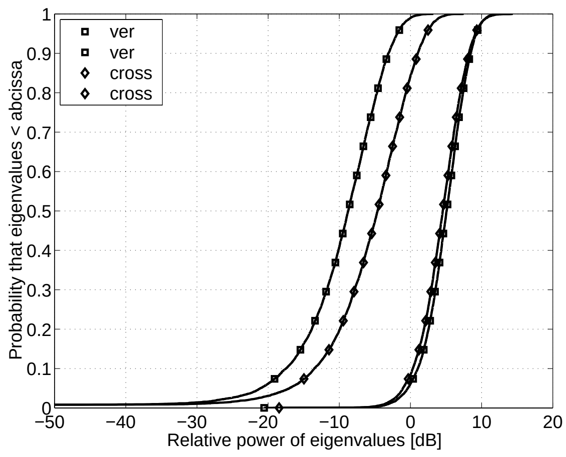


b)

Fig. 3. Mean capacity of the investigated MIMO systems as a function of ρ. (4) used in normalization. a) microcell. b) small macrocell.



a)



b)

Fig. 4. Eigenvalues of the investigated MIMO systems. (4) used in normalization. a) microcell. b) small macrocell.

V. CONCLUSION

Traditionally eigenvalue spread is used as a figure of merit for MIMO systems. However, eigenvalue spread alone is not adequate quality factor for MIMO systems but total transferred power is also needed. Thus, we have proposed an extension of the Mean Effective Gain (MEG), which is called the Mean Effective Link Gain (MELG), for MIMO systems. The MELG characterizes the capability of the antennas to transfer signal power from transmitter to receiver, whereas eigenvalue spread measures the capability of the propagation environment and the antennas to create parallel data "pipes". We stress that neither of these measures alone is sufficient to evaluate the performance of MIMO system. We have shown that MIMO system having a narrower eigenvalue spread does not necessarily provide higher capacity if it's MELG is lower. We have also proved that the normalization of the results is critical issue in MIMO considerations. The total transferred power will be wrongly predicted if the same normalization antennas (same reference) are not used for the comparison of different MIMO systems.

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