Receive Antenna Selection for Polarized Antennas

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***Abstract*—In this work we analyze the combined effects of array orientation/rotation and antenna cross polarization discrimination on the performance of dual-polarized systems with receive antenna selection. We start our analysis with a 1 out of N selection and extend it to M out of N receive antenna selection, for which we derive numerical expressions for the effective channel gains. These expressions are valid for small values of M and N, and approximately valid for higher values of M and N. Our analysis shows that robustness against rotation increases as the number of selected antennas is increased. We conclude from our analysis that M needing to be at least $1/2$ of N, the maximum effective channel gain can be attained.**

Keywords-Antenna Selection, XPD, Array orientation, Array rotation.

I. INTRODUCTION

In the analysis of multiple-input multiple-output (MIMO) systems, an array of vertical antennas is normally considered when the receiver has no space limitations. In compact portable devices, such as mobile handsets and laptops, if a spatial array of vertical antennas is realized, high correlation between the closely spaced antenna elements severely effects the performance. Applying dual polarized antennas at the receiver or at the transmitter proves effective in alleviating performance loss due to low correlation between the antenna elements. Antenna selection, when combined with dual-polarized antennas, enables compact devices to exploit the benefits of the MIMO architecture with only a nominal increase in complexity. Also there can be a leakage of power from one antenna to another. This effect is known as antenna Cross Polarized Discrimination (XPD), and is eminent in both co-located dual-polarized antenna arrays and spatially separated antenna arrays. The effect of correlation is more dominant in closely spaced antenna arrays and less dominant in systems with dual-polarized antennas. XPD is due to non-ideal antenna polarization patterns. Because of this leakage, a simple rotation in the antenna array causes a mismatch in the incoming incident Electro-Magnetic (EM) wave. The amount of this leakage has an impact on the overall performance of the system [1]. Multiple Dual Polarized (DP) antennas are strong candidates to be put into practice in 3GPP Long Term Evolution (LTE) [2] systems.

A. Motivation and Contribution

Antenna arrays combined with receive antenna selection techniques can improve the quality of wireless communication systems through reduction of fading impact. If a dual-polarized receive antenna is employed, a further benefit is the mitigation of polarization mismatch caused by the random orientation of portable devices. Increased hardware complexity is a considerable disadvantage for deploying MIMO. Conventional MIMO systems require one down-conversion/up-conversion radio frequency (RF) chain for each antenna element. While the antenna elements themselves do not increase transceiver costs significantly, the RF chains are a very significant cost factor. Antenna subset selection techniques help in cost reduction for MIMO deployment, while maintaining full MIMO diversity benefits. In this work multiple co-located (fed from the same point) receive antennas are considered. We apply Receive Antenna Selection (RAS), starting with 1 out of 2 selection and then extend our work to 1 out of N receive antennas. Finally, the results are generalized for the M out of N selection case to study the limits on performance. The combined effect of array rotation, power imbalance, and M out of N receive antenna selection is studied. Analysis and simulation is performed for flat Rayleigh fading channels. Accurate expressions and approximate bounds for the effective channel gains are provided for a generic M out of N selection. A simple Maximum Ratio Combiner (MRC) is applied at the receiver for signal detection. Robustness analysis is presented for a generic M out of N receive antenna selection by finding the CDF of the effective channel gains through simulations. From limiting values of effective channel gains, a minimum antenna set (M, N) is found. To the best of our knowledge the features enumerated above have not been analyzed collectively for a MIMO system in literature.

B. Related Work

1) Dual Polarized Antenna Modeling: The utilization of multiple polarizations of the electromagnetic wave to extract diversity has been well known and understood for a long time [3]. The capacity of the dual polarized MIMO channel is evaluated and compared to the capacity of a single polarized MIMO system. In [4] [5], the potential advantages of employing dual-polarized arrays in multi-antenna wireless systems for various channels is studied. In [6] [7], a model is proposed to determine the XPD as a function of the channel condition under different antenna configurations. In this paper it is shown that the antenna XPD is not only sensitive to different channel conditions but also to different receiver orientations.

2) Dual polarized MIMO with rotation: In [8] the impact of the polarization on the performance of the MIMO channel with cross-polarized antennas has been investigated based on an outdoor macro-cell measurement at 2.53 GHz. A simple model which can capture the major characteristics of the cross polarized channel has been proposed. It has been shown that the polarization diversity outperforms the spatial diversity in a Line Of Sight (LOS) scenario, but shows relatively small gain in a rich scattering scenario.

3) Antenna Selection: In [9] [10] selection algorithms for maximizing the channel capacity are presented together with performance measures. It was proved that the diversity order achievable by antenna selection is the same as that of a full complexity system. In [11] [12], a criteria for selecting the optimal antenna subset when linear coherent receivers are realized over a slowly varying channel has been presented. In [13], receive antenna subset selection schemes are applied in a MIMO-OFDM transmission system. Simulation results in terms of average throughput and Bit Error Ratio (BER) on an adaptive modulation and coding link have been shown.

4) Antenna selection for dual polarized MIMO: In [14], the performance of antenna selection on dual polarized MIMO channels with linear Minimum Mean Square Error (MMSE) receiver processing is analyzed. A study on the impact of XPD on the achieved selection gain is carried out. BER results obtained indicate that antenna selection with dual-polarized antennas can achieve significant performance gains for compact configurations. In [15], dual polarized MIMO exploiting the Spatial Channel Model (SCM) [16] is investigated in terms of performance for a certain environment. Applying this channel model, the channel capacity is estimated as a function of the XPD and the spatial fading correlation. The remainder of the paper is organized as follows. Section II presents the system model for an MRC receiver for different antenna configurations. Antenna XPD and channel gains for SISO, single-input multiple-output (SIMO) with and without receive antenna selection is calculated. In Section III an analysis on the average values of the channel gains is presented for the most simple antenna configurations. The results calculated here are generalized to a higher number of receive antennas along with a few approximations. Maximum values of channel gains are also calculated analytically and through simulation. To attain these limiting values of the effective channel gains, the antenna set (M, N) is found which has the minimum number of elements. An analysis of the robustness against channel variations, by calculating the CDFs of the channel gains, is presented in Section IV. Section V concludes the paper.

II. SYSTEM MODEL WITH ROTATION AND XPD

The rotation of an antenna array can be modeled by multiplying the channel matrix with a rotation matrix [8]. If we define the amount of energy leakage between the two polarizations of an antenna as α, the antenna XPD is specified by [1], $\mathrm{XPD} = \frac{1-\alpha}{\alpha}$ where $0 \leq \alpha \leq 1$. Therefore when

$$\lim_{\alpha\to 0} \mathrm{XPD} = \infty; \qquad \lim_{\alpha\to 1} \mathrm{XPD} = 0.$$

All antenna elements considered in this work are assumed as simple monopoles. The transmitter contains a single vertically polarized antenna and the receiver consists of N antenna elements in an N-spoke configuration [17], as shown in Fig. 1. The feeding points of all antenna elements are co-located. In [17], a similar antenna configuration is used to compare polarization diversity to spatial diversity. We further assume that the antenna elements are isotropically radiating in all directions with unity gain and there is no angular correlation between them. Note that in a practical system, a certain amount of correlation exists between the antenna elements, as calculated in [17], [18], [19]. In order to be able to derive analytical expressions for the channel gains, however, we will neglect the angular correlation here.

A. General MRC Receiver

The model for a generic $1\times N$ SIMO system with maximum ratio combining is explained in the following. Subsequently a model for RAS with MRC will be shown. The channel matrix is written as

$$\mathbf{h} = [h_1, h_2, \cdots, h_N]^{\mathrm{T}},$$

and the received signal vector by

$$\mathbf{y} = \mathbf{h} \cdot x + \mathbf{v}, \tag{1}$$

where $x \in \mathcal{C}$ and $\mathbf{v} \in \mathcal{C}^N$ with $\mathbf{v}$ being a noise vector with i.i.d and circularly symmetric complex-valued Gaussian entries with variance 1/2 σ_v^2 for each real dimension. The detected symbol at the MRC output is shown as

$$\hat{x} = \mathbf{h}^{\mathrm{H}} \cdot \mathbf{h} \cdot x + \mathbf{h}^{\mathrm{H}} \cdot \mathbf{v}, \tag{2}$$

where $(\cdot)^{\mathrm{H}}$ denotes the Hermitian. The received signal for receive antenna selection is then given by

$$\mathbf{y}^{(\mathcal{S_M})} = \mathbf{h}^{(\mathcal{S_M})} \cdot x + \mathbf{v}^{(\mathcal{S_M})}, \tag{3}$$

where the MRC only combines the received signals from the selected antennas identified by the set of indices of an ordered set $\mathcal{S_M} = \{n_1, n_2, \cdots, n_M\}$ where $n_i \in [1, 2, \cdots, N]$. The detected symbol after receive antenna selection is then

$$\hat{x}^{(\mathcal{S_M})} = \mathbf{h}^{(\mathcal{S_M})\mathrm{H}} \cdot \mathbf{h}^{(\mathcal{S_M})} \cdot x + \mathbf{h}^{(\mathcal{S_M})\mathrm{H}} \cdot \mathbf{v}, \tag{4}$$

The gain of full complexity receiver is given by

$$G_{N/N} = E\left[\mathbf{h}^{\mathrm{H}} \cdot \mathbf{h}\right], \tag{5}$$

while the gain of receiver with antenna selection is given by

$$G_{M/N} = E\left[\mathbf{h}^{(\mathcal{S_M})\mathrm{H}} \cdot \mathbf{h}^{(\mathcal{S_M})}\right]. \tag{6}$$

A generic model of the system is shown in Fig. 1 with all the essential components. We assume here for simplicity that the channel is known at the receiver and there is a perfect synchronization between the transmitter and the receiver. Also we do not dwell into the practicalities of the switch and the RF chain. We assume an ideal switch without any insertion losses. We further assume that the channel does not change during the switching period.

B. SIMO $1 \times N$ with polarization

The receiver is assumed to be randomly oriented in space. Due to this a polarization mismatch loss can occur as dis-

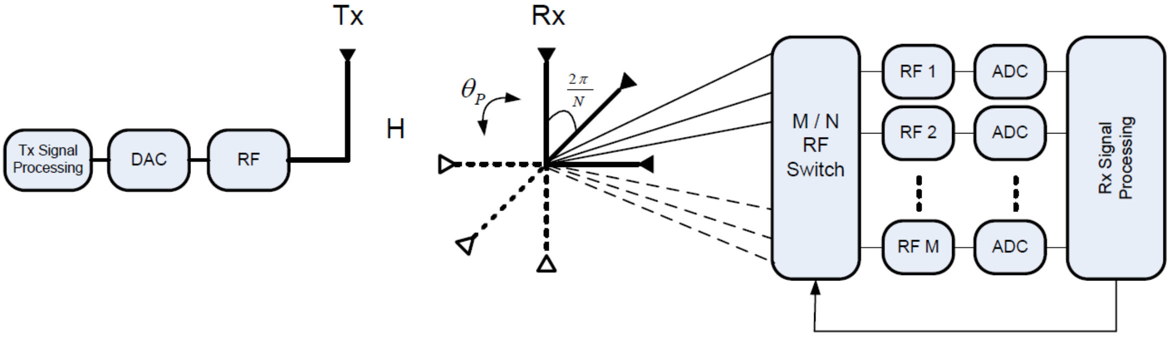

Fig. 1. N-Spoke antenna configuration (1 Tx and N Rx) with receive antenna selection.

cussed in [20]. The orientation can be represented in a three dimensional co-ordinate system, but here, for simplicity we only consider one direction so that the orientation/rotation is represented by a single angle θ_p with respect to the vertical antenna element of the array. The effect of antenna orientation is well discussed in [21] [22]. The averaging is hence performed for all the rotation angles. We start with the analysis of a single receive antenna case. The channel matrix is multiplied with an XPD matrix and then with a rotation matrix as shown in [8]. A simple model which can identify the basic characteristics of the polarized MIMO channel is proposed in this work [8]. This model can describe the cross-polarized channel in realistic scenario better. The power is divided into each orthogonal component of antenna element as shown in Fig. 2. Next we show simulations for $1 \times N$ SIMO with MRC at the receiver. The channel matrix for $1 \times N$ SIMO is

$$\mathbf{h}_N = \begin{bmatrix} h_1\left(\sqrt{1-\alpha}\cos(\theta_p + k_1\frac{2\pi}{N}) + \sqrt{\alpha}\sin(\theta_p + k_1\frac{2\pi}{N})\right) \\ h_2\left(\sqrt{1-\alpha}\cos(\theta_p + k_2\frac{2\pi}{N}) + \sqrt{\alpha}\sin(\theta_p + k_2\frac{2\pi}{N})\right) \\ \vdots \\ h_N\left(\sqrt{1-\alpha}\cos(\theta_p + k_N\frac{2\pi}{N}) + \sqrt{\alpha}\sin(\theta_p + k_N\frac{2\pi}{N})\right) \end{bmatrix}, \tag{7}$$

where $k_N = n; n = 0, 1, \cdots, N-1$ and $0 \leq \alpha \leq 1$. As we have realized an MRC receiver, we sum the squares of the channel coefficients for each row of the channel matrix in Eq. (7) and take the average over all realizations. The effective channel gain is then shown by Eq. (10). In Fig. 3, a 1×3 SIMO antenna configuration is shown as an example.

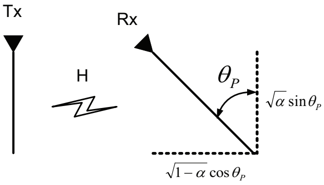

Fig. 2. Orthogonal polarization components of SISO receive antenna.

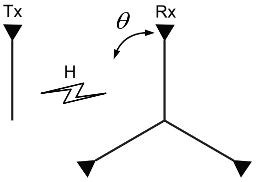

Fig. 3. 1×3 SIMO antenna configuration.

C. RAS $1/N$ and M/N with polarization

Next we simulate the effect of XPD and rotation on the channel gains of $1/N$ RAS. The notation M/N is used to denote receive antenna selection, selecting M out of N receive antennas. We start by selecting $M = 1$ out of N from the channel matrix given by Eq. (7), with the largest norm, $\bar{n} \in [1, 2, \cdots, N]$ being the index of the selected antenna element. The corresponding channel coefficient $h_{1/N}$ becomes a scalar.

$$h_{1/N} = \left[h_{\overline{n}}\left(\sqrt{1-\alpha}\cos\left(\phi_{\overline{n}}\right) + \sqrt{\alpha}\sin\left(\phi_{\overline{n}}\right)\right)\right], \tag{8}$$

where $\phi_{\overline{n}} = \theta_p + k_{\overline{n}}\frac{2\pi}{N}$. The effective channel gain is expressed in Eq. (11). A similar matrix $\mathbf{h}_{M/N} = [h_1, h_2, \cdots, h_M]^T$ can be constructed, containing only the channel coefficients of the M selected antenna elements, indices of which would be from an ordered set given by $\mathcal{S}_{\mathcal{M}} = \{n; \|h_n\|_F > \|h_{M+1}\|_F\} = [n_1, n_2, \cdots, n_M]$. The new channel matrix with M/N selection is then

$$\mathbf{h}_{M/N} = \begin{bmatrix} h_{n_1}\left(\sqrt{1-\alpha}\cos(\phi_{n_1}) + \sqrt{\alpha}\sin(\phi_{n_1})\right) \\ h_{n_2}\left(\sqrt{1-\alpha}\cos(\phi_{n_2}) + \sqrt{\alpha}\sin(\phi_{n_2})\right) \\ \vdots \\ h_{n_M}\left(\sqrt{1-\alpha}\cos(\phi_{n_M}) + \sqrt{\alpha}\sin(\phi_{n_M})\right) \end{bmatrix}, \tag{9}$$

where $\phi_{n_m} = \theta_p + k_{n_m}\frac{2\pi}{N}$.

III. ANALYTICAL CALCULATIONS FOR AVERAGE VALUES OF CHANNEL GAINS AND GENERALIZATION

To find the average values analytically over all $\alpha's$ and over all $\theta_p's$ we do the following for $1/2$ RAS. As $E\left\|h_1^2\right\| = E\left\|h_2^2\right\| = 1$ for Rayleigh fading channels, we deduce the following inequality from an approximation of Eq. (11) given in Eq. (12):

$$\left(\sqrt{1-\alpha}\cos\theta_p + \sqrt{\alpha}\sin\theta_p\right)^2 > \left(\sqrt{1-\alpha}\sin\theta_p + \sqrt{\alpha}\cos\theta_p\right)^2.$$

Solving the inequality for $\alpha = 0$ we find that $\cos^2\theta_p > \sin^2\theta_p$, which results in the interval $0 < \theta_p < \frac{\pi}{4}$ and

$$G_{1/2,\alpha=0} = \frac{4}{\pi}\int_0^{\frac{\pi}{4}} \left(\cos^2\theta_p\right) d\theta_p = 0.8183.$$

$$G_{N/N}(\theta_p) = \sum_{n=1}^{N} E\left[|h_n|^2 \left(\sqrt{1-\alpha}\cos\left(\theta_p + \frac{(n-1)2\pi}{N}\right) + \sqrt{\alpha}\sin\left(\theta_p + \frac{(n-1)2\pi}{N}\right)\right)^2\right]. \tag{10}$$

$$G_{1/N}(\theta_p) = E\left[\max\left\{|h_1|^2\left(\sqrt{1-\alpha}\cos(\phi_1) + \sqrt{\alpha}\sin(\phi_1)\right)^2, \cdots, |h_N|^2\left(\sqrt{1-\alpha}\cos(\phi_N) + \sqrt{\alpha}\sin(\phi_N)\right)^2\right\}\right]. \tag{11}$$

$$G_{1/N}(\theta_p) \approx \max\left\{E\left[|h_1|^2\right]\left(\sqrt{1-\alpha}\cos(\phi_1) + \sqrt{\alpha}\sin(\phi_1)\right)^2, \cdots, E\left[|h_N|^2\right]\left(\sqrt{1-\alpha}\cos(\phi_N) + \sqrt{\alpha}\sin(\phi_N)\right)^2\right\}. \tag{12}$$

where $\phi_n = \theta_p + k_n\frac{2\pi}{N}$.

$$\left(\sqrt{1-\alpha}\cos\theta_p + \sqrt{\alpha}\sin\theta_p\right)^2 > \left(\sqrt{1-\alpha}\cos\left(\theta_p + \tfrac{2\pi}{3}\right) + \sqrt{\alpha}\sin\left(\theta_p + \tfrac{2\pi}{3}\right)\right)^2 > \left(\sqrt{1-\alpha}\cos\left(\theta_p + \tfrac{4\pi}{3}\right) + \sqrt{\alpha}\sin\left(\theta_p + \tfrac{4\pi}{3}\right)\right)^2. \tag{13}$$

$$G_{N/N} = \frac{1}{2\pi}\int_0^{2\pi}\left[\sum_{n=1}^{N} E\left\{|h_n|^2\left(\sqrt{1-\alpha}\cos\left(\theta_p + \frac{(n-1)2\pi}{N}\right) + \sqrt{\alpha}\sin\left(\theta_p + \frac{(n-1)2\pi}{N}\right)\right)^2\right\}\right] d\theta_p. \tag{14}$$

$$G_{2/N} = \frac{2N}{\pi}\int_0^{\frac{\pi}{2N}}\cos^2(\theta_p)\,d\theta_p + \frac{N-1}{\pi}\int_0^{\frac{\pi}{N-1}}\cos^2(\theta_p)\,d\theta_p. \tag{15}$$

Similarly from Eq. (12) for $1/3$ RAS, we obtain the inequality (13). Now solving the inequality in (13) for $\alpha = 0$ we find that $\cos^2\theta_p > \cos^2\left(\theta_p + \frac{2\pi}{3}\right) > \cos^2\left(\theta_p + \frac{4\pi}{3}\right)$ which results in the interval $0 < \theta_p < \frac{\pi}{6}$ and

$$G_{1/3,\alpha=0} = \frac{6}{\pi}\int_0^{\frac{\pi}{6}}\cos^2\theta_p d\theta_p = 0.9135.$$

Eq.(12) can be solved for other values of α, but the calculations are not shown here for space limitations.

A. SIMO $1 \times N$

For SIMO we have the relation depicted in Eq. (14). This gives the average effective channel gains to be

$$G_{N/N} = \frac{1}{2}N. \tag{16}$$

We observe that the relation is very simple and only a linear function of N.

B. RAS $1/N$

The intervals calculated in the previous section, show that they are multiples of $\frac{\pi}{2N}$. Hence we obtain the following relations.

$$G_{1/N,\alpha=0} = \frac{2N}{\pi}\int_0^{\frac{\pi}{2N}}\cos^2\theta_p d\theta_p = \frac{1}{2} + \frac{N}{\pi}\sin\frac{\pi}{2N}\cos\frac{\pi}{2N}. \tag{17}$$

We recognize that the relation is a function of simple trigonometric identities.

C. RAS M/N

Now we derive the expression for an M/N selection. We derive the result for $2/3$ and $2/4$ RAS and then generalize it. The first inequality shown below yields the largest interval corresponding to the largest channel gain.

$$\cos^2\theta_p > \cos^2\left(\theta_p + \frac{2\pi}{3}\right) > \cos^2\left(\theta_p + \frac{4\pi}{3}\right),$$

$0 < \theta_p < \frac{\pi}{6}$, and the second largest inequality below gives the second largest interval

$$\cos^2\left(\theta_p + \frac{2\pi}{3}\right) > \cos^2\left(\theta_p + \frac{4\pi}{3}\right),$$

$0 < \theta_p < \frac{\pi}{2}$. Calculating the gains from these intervals and summing them gives

$$G_{2/3,\alpha=0} = \frac{6}{\pi}\int_0^{\frac{\pi}{6}}\cos^2\theta_p d\theta_p + \frac{2}{\pi}\int_0^{\frac{\pi}{2}}\cos^2\theta_p d\theta_p. \tag{18}$$

With the same procedure above we find the channel gains for $2/4$ selection

$$G_{2/4,\alpha=0} = \frac{8}{\pi}\int_0^{\frac{\pi}{8}}\cos^2\theta_p d\theta_p + \frac{3}{\pi}\int_0^{\frac{\pi}{3}}\cos^2\theta_p d\theta_p. \tag{19}$$

After generalization we reach to Eq. (15). For values of $M > 2$, it is very tedious to solve the inequalities. These inequalities can be solved numerically through MATLAB or MAPLE software tools or an approximate solution can be presented, as shown here with the advantage to obtain some explicit formulations. For approximation we just added the first M terms of $G_{1/N}$ from Eq. (17), but with $\frac{\pi}{n}$ instead of $\frac{\pi}{2n}$ intervals, as listed below.

$$G_{3/N,\alpha=0} \approx \left[\sum_{n=N-3}^{N-1}\frac{n}{\pi}\int_0^{\frac{\pi}{n}}\cos^2(\theta_p)\,d\theta_p\right]. \tag{20}$$

$$G_{4/N,\alpha=0} \approx \left[\sum_{n=N-4}^{N-1}\frac{n}{\pi}\int_0^{\frac{\pi}{n}}\cos^2(\theta_p)\,d\theta_p\right]. \tag{21}$$

$$G_{5/N,\alpha=0} \approx \left[\sum_{n=N-5}^{N-1}\frac{n}{\pi}\int_0^{\frac{\pi}{n}}\cos^2(\theta_p)\,d\theta_p\right]. \tag{22}$$

$$G_{M/N,\alpha=0} \approx \left[\sum_{n=N-M}^{N-1}\frac{n}{\pi}\int_0^{\frac{\pi}{n}}\cos^2(\theta_p)\,d\theta_p\right]. \tag{23}$$

Monte-Carlo simulations are performed to generate channel coefficients according to Eq. (7) for SIMO and Eq. (8) for selection systems for $\alpha = 0$ and averaged over rotation angles. Results from these expressions and comparison with simulation are shown in Fig. 4. Theoretical results are shown in dotted and simulations in solid lines. It can be observed that the curves for $1/N$ and N/N receive antenna selection serve as lower and upper bound respectively, for the channel

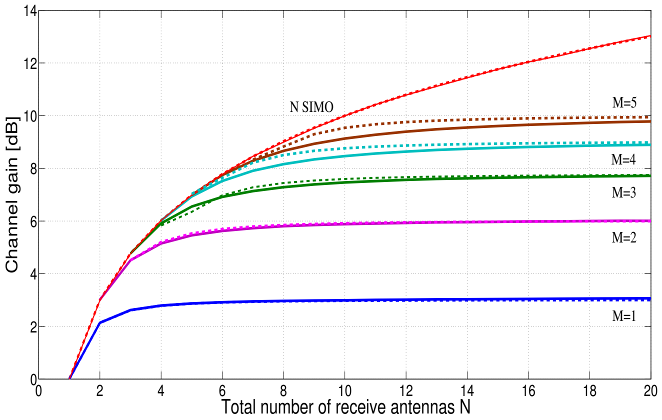

Fig. 4. Channel gains for $1 \times N$ SIMO and M/N RAS wrt. SISO.

gains of M/N RAS.

D. *Limiting Values for M/N RAS*

Next we derive the limiting values of M/N RAS analytically.

$$\lim_{N\to\infty} G_{M/N} = \lim_{N\to\infty}\left[\sum_{n=N-M}^{N-1} \frac{n}{\pi}\int_0^{\frac{\pi}{n}} \cos^2\left(\theta_p\right) d\theta_p\right] \tag{24}$$

$$= M\left(1 + \lim_{N\to\infty} \frac{N}{2\pi}\sin\frac{2\pi}{N}\right), \tag{25}$$

$$= M\left(1 + \lim_{x\to 0}\frac{1}{x}\sin(x)\right), \tag{26}$$

$$= 2M, \tag{27}$$

for $M = 1, 2, 3, 4, \ldots .N$. Various values of M and corresponding actual selection gains in the limit, are shown in the Table I. The analytical expressions for values $M > 2$ as seen from the curves in Fig. 4, serve as an upper bound. The difference between the effective channel gains decreases as M is increased for a given N. This happens because of the dependence of mean channel gains on the average angular separation $\frac{2\pi}{N}$ between M selected antennas. As M is increased the average angular spacing between the selected antennas is decreased, so does the difference. From Fig. 4 we observe that the channel gains almost attain their maximum values after a certain number of antenna elements N.The total number of used antennas can be reduced without compromising much performance. From the graph, for each M/N curve, we can find out the minimum N which gives almost 100% of the maximum value of the channel gains. The results of calculating the minimum set is shown in Table I. The first column shows the value of the number of selected antennas M. In the second column the maximum value of the channel gains are given from Eq. (27). The third column shows the values of N required to achieve a certain percentage of the maximum channel gain. The achieved gains and corresponding used percentages, are shown in the next columns. If we take 95% of the maximum value as an example, the loss in the gains is not much but we can save a number of antenna elements. From the table it is conlcuded that M should be at least half of the total number of receive antennas to achieve almost the maximum performance.

TABLE I
MINIMUM RECEIVE ANTENNA SET (M, N) TO ACHIEVE THE MAXIMUM % OF GAIN.

M	Max.Gain	Req.N	Ach.Gain	Ach.Gain %
1	3.01	2	2.85	95
2	6.02	4	5.72	95
3	7.78	6	7.39	95
4	9.03	8	8.57	95
5	10	10	9.5	95

IV. ROBUSTNESS ANALYSIS

The CDF plots shown here provide the measure of robustness against antenna rotation and orientation. It also reveals the measure of variance of channel gains. In Fig. 5 we show CDF plots for $1/N$ RAS. From the plots we observe that as N increases, the slopes of the curves increase, and the corresponding range of the gains decrease and hence robustness against channel variations increases. As seen from the graphs, variance depends on the available diversity branches N. Also it can be observed that the mean of the channel gain is dependent on the number selected antenna M. The ratio $\frac{M}{N}$ shows as the inverse of the slope. Therefore as N increases, the slope increases and hence the decrease in variance. In Fig. 6 we show the CDF plot for $2/N$ RAS. A behavior similar to $1/N$ RAS, can be found in this plot i.e. the slope increases as N increases. In Fig. 7 we show the comparison of CDF plots for various values of $M/10$ receive antenna selection.

V. CONCLUSIONS

We derived expressions for the mean channel gains of SIMO systems with a dual-polarized N-spoke configuration for a Rayleigh fading environment with receive antenna selection. The effect of power imbalance within antenna elements and antenna orientation, combined with the benefits of receive antenna selection, was studied. The results of analytical expressions and simulations were compared. Various antenna combinations were studied and the numerical expressions were generalized. Robustness analysis was performed by simulating the CDF of the effective channel gains. The expressions presented for M/N receive antenna selection are functions of simple trigonometric identities. A minimum antenna set, which gives near best performance, was found through the analysis and simulations.

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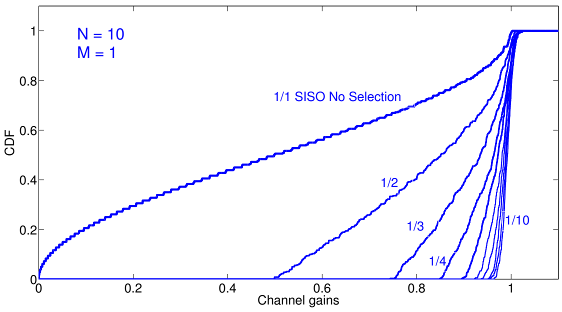

Fig. 5. CDF of channel gains for M/N where $N = 1, ...10, M = 1$.

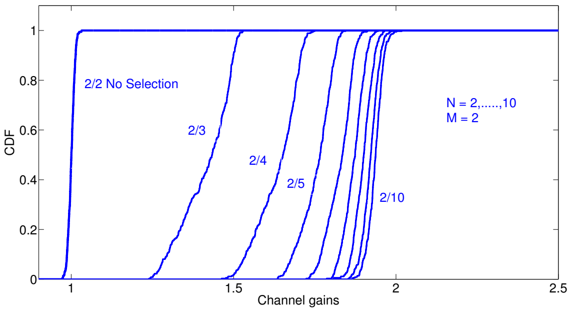

Fig. 6. CDF of channel gains for M/N where $N = 2, ...10, M = 2$.

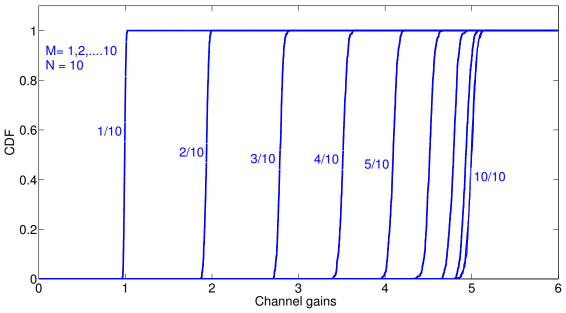

Fig. 7. CDF of channel gains for M/N where $N = 10, M = 1, ...10$.

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