Investigation of the influence of antenna array parameters on adaptive MIMO performance

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Abstract
This paper presents an investigation for adaptive parameters of multi-antenna schemes for its use in future reconfigurable MIMO systems. The study puts a special emphasis in linking the concept of channel diversity, either in the spatial or polarization domain, with the type of polarization being used both at the transmitter (TX) and receiver (RX), and the level of multipath provided by the channel in the vertical or horizontal direction, with respect to the propagation plane. It has been found that NLOS indoor channels are very sensitive to type of signal diversity being employed and the type of polarization and component of the multipath being used.

Introduction
Next generation of wireless communication networks and terminals will introduce stringent requirements to satisfy: high data rate capacities over a large variety of environments under limited resources of bandwidth and signal power. Capacity, bandwidth and signal power are inter-related as stated on the Shannon equation for single-input single-output (SISO) communications. This equation tells us that employing SISO schemes cannot satisfy those new requirements. New techniques based on multi-antenna schemes have been investigated to overcome this limitation. Receiving diversity is a relatively new technique that can be classified into single-input multiple-output (SIMO) communication schemes. It employs multiple antennas at the receiver to mitigate the multipath phenomena and hence increases the received average signal power level. Beamforming is another technique. In contraposition, other techniques exploit the multipath phenomena. They are known as transmitting diversity schemes and they are based on MISO and MIMO schemes. They use space-time codes to exploit the multipath phenomena and overcome the limitation in capacity experienced by SISO schemes.

In this investigation we intent to characterize the interaction of a multi-antenna system for a typical indoor channel in spatial and polarization domain. Spatial and polarization signal diversity techniques over a non-line of sight (NLOS) channel are considered. Angle domain results including the mutual coupling effect and LOS measurements will be included in the conference presentation. The orientation of each scheme and the type of polarization used at both the transmitter and the receiver are taken into account. They are some of the adaptive parameters for MIMO systems. From the conducted experiments we calculate power imbalance and correlation coefficient. This paper shows a part of a more extended work in adaptive MIMO systems.

The operating frequency was fixed to 2.45GHz. The area occupied by all the antenna schemes and the type of radiating antenna element were fixed in all the schemes. This allowed us to compare the different antenna schemes with the same antenna radiation characteristic and consider the fact that the performance of those schemes is inherently related with the number of antennas used at the same time.

Description of the signal diversity concept
Space and polarization are the two dimensions considered in this study as adaptive parameters that can provide signal diversity in a multi-antenna base system with reconfigurability features.
Spatial and polarization diversity of an indoor channel is the capability of the channel to provide uncorrelated signals, due to the multipath phenomena, between antennas separated by a given distance, and to different polarizations of the electric field at a given position, respectively.

**Description of the fundamental radiating antenna element**
The RX radiating antenna element, that was employed in all the multi-antenna schemes, was chosen to be a coupled microstrip fed annular slot ring antenna (ARSA) [1], fabricated on RT/Duroid Roger 5695, with dielectric constant $\varepsilon = 2.50$ and thickness $h = 1.1938\text{mm}$. Linearly polarized ARSA provides an input impedance bandwidth of 11% while circularly polarized ARSA has an impedance bandwidth of 12.6% and an axial ratio bandwidth of 7%. Both configurations provide an omnidirectional radiation pattern in the transversal plane to the board.

**Description of the experimental conditions**
The results presented in this paper obtained from experiments conducted in a typical NLOS indoor channel. All the diversity schemes, at the RX, were based on two antenna element arrays, with antennas separated by a distance of $0.4\lambda$. At the TX, a dipole was used to radiate vertically linearly polarized waves and an ARSA was used to radiate circularly polarized waves.

**Results concerning the characterization of a NLOS indoors channel**

*Spatial signal diversity*

Employing linearly polarized antennas at the RX for spatial signal diversity schemes, independent from the type of polarization at the TX, the vertical and horizontal component of the field provides similar levels of spatial signal diversity. However this depends on the geometry of the environment. In particular for our case, the horizontal component provided slightly larger spatial diversity than the vertical component. In addition, when linearly polarized antennas are used at both the TX and RX, a 45 degree rotation of the scheme with respect to the azimuth or the vertical, lowers the spatial diversity due to the projected centers of the antennas over the horizontal or vertical, are closer than in the non-rotated version, and hence cannot provide the same level of polarization.

For spatial diversity schemes with a linearly polarized antenna at the TX, the spatial signal diversity is slightly larger (1dB to 2dB larger diversity gain) when employing linearly polarized antennas than when using circularly polarized antennas at the RX. However, when using a circularly polarized antenna at the TX, the spatial signal diversity is approximately the same regardless of the type of polarization used at the RX.

Spatial diversity schemes with a 45 degrees rotation with respect to the azimuth are favorable (slightly larger diversity gain) when employing circularly polarized antennas at the RX and regardless of the polarization of the TX. This provides lower correlation coefficient and power imbalance between branches. However, this rotation is not favorable when employing linearly polarized antennas at the RX, independent from the TX polarization, because it increases the power imbalance and the correlation between antennas.

It has been observed that using spatial diversity schemes and linearly polarized antennas at both the TX and the RX, vertically linearly polarized RX schemes provide larger spatial signal diversity when the antennas are place in the azimuth (please see Fig. 1 scheme A) direction than when placed in the vertical direction. Horizontally linearly polarized RX schemes provide larger spatial signal diversity when the antennas are distributed in the vertical direction (please see Fig. 1, scheme A).

*Polarization signal diversity*

Employing polarization diversity schemes with linearly polarized antennas in the RX, and independent from the type of polarization used at the TX, the signal diversity provided by the channel, in the direction perpendicular to the propagation plane (vertical direction) is smaller than in the azimuthal (horizontal) direction. That is, a diversity gain of 3.62dB is obtained in the
vertical plane versus 6.65dB in the horizontal plane, for linearly polarized TX. Similarly, 3.79dB are obtained in the vertical plane versus 6.08dB in the horizontal plane, for circularly polarized TX). This phenomenon can be explained by the fact that in the vertical direction, the power imbalance between branches is very large. However, when linearly circularly polarized antennas are being used at the RX, the signal diversity is larger in the vertical direction than in the horizontal one (6.2dB of diversity gain versus 5.6dB, for linearly polarized TX, and 6.97dB of diversity gain versus 5.15dB, for circularly polarized TX). It is proven that when polarization diversity is considered, the channel has a strong sensitivity to the type of polarization being used and the orientation of the diversity scheme (multipath of diversity component). In this case, the higher diversity in the vertical direction can be explained by having lower correlation between branches.

In polarization diversity schemes, it has been observed that when using circularly polarized antennas at the RX, and depending on the direction being considered (vertical or horizontal), the values of signal diversity varies much less (0.8dB to 1.5dB variation) in comparison with the configurations that uses linearly polarized antennas at the RX (2.5dB to 3dB variation). However, the diversity is slightly better in the vertical direction. Hence, circular polarization diversity schemes at the RX seem to be more robust in front of possible rotations of the receiver.

From the measurements, it was observed that in any configuration of type of polarization, all the polarization diversity schemes offers lower correlation coefficient between branches in comparison with spatial diversity schemes. Hence, in most of the cases the signal diversity gain is larger.

**Signal diversity versus the area of the antenna system**

Using linearly polarized antennas at both the TX and the RX, pure polarization diversity schemes (one antenna dual polarized) provide similar levels of diversity than pure space diversity schemes (3.1dB gain vs. 3.4dB gain, respectively). However, by fixing the number of branches to two, pure polarization schemes occupies half of the area. This shows the potential of polarization signal diversity for future adaptive MIMO systems.

In this study, the polarization diversity schemes have inherent spatial diversity that cannot be ignored. For this reason the performance of those schemes is in general better than any spatial diversity scheme [2]. In addition, this is true for any combination of type of polarization being used at the TX and the RX, except in the case where linearly polarized antennas are being used at the RX and the schemes are vertically oriented. Hence, in general, the combination of both diversities provides a way to increase the signal diversity for a fixed area reserved to the antenna system.

**Summary of the results for the conducted experiments**

Figure 1 shows the spatial (schemes A, B for linearly polarized antennas, and scheme D for circularly polarized antennas) and polarization (scheme C for linearly polarized antennas, and scheme E for circularly polarize antennas) diversity schemes that have been employed on this investigation. Table 1 summarizes the results of the measurements concerning this paper.

<table>
<thead>
<tr>
<th>Polarization TX</th>
<th>Polarization RX</th>
<th>RX scheme</th>
<th>RX rotation (degrees)</th>
<th>Diversity type</th>
<th>Studied field component</th>
<th>Diversity gain (dB)</th>
<th>Correlation coefficient</th>
<th>Power imbalance (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear</td>
<td>Linear</td>
<td>A</td>
<td>0</td>
<td>Spatial</td>
<td>Vertical</td>
<td>5.92</td>
<td>0.194</td>
<td>-1.28</td>
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<tr>
<td>Linear</td>
<td>Linear</td>
<td>B</td>
<td>45</td>
<td>Spatial</td>
<td>Vertical</td>
<td>5.34</td>
<td>0.130</td>
<td>1.14</td>
</tr>
<tr>
<td>Linear</td>
<td>Linear</td>
<td>B</td>
<td>-45</td>
<td>Spatial</td>
<td>Horizontal</td>
<td>5.66</td>
<td>0.376</td>
<td>-2.47</td>
</tr>
<tr>
<td>Linear</td>
<td>Linear</td>
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<td>90</td>
<td>Spatial</td>
<td>Horizontal</td>
<td>5.86</td>
<td>0.352</td>
<td>-0.42</td>
</tr>
<tr>
<td>Linear</td>
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<td>Polarization</td>
<td>Vertical and Horizontal</td>
<td>6.65</td>
<td>0.0357</td>
<td>-1.19</td>
</tr>
<tr>
<td>Linear</td>
<td>Linear</td>
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<td>45</td>
<td>Polarization</td>
<td>Vertical and Horizontal</td>
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<td>0.0376</td>
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</table>
A typical NLOS indoor channel is sensitive to the type of signal diversity employed, the type of polarization being used and direction of multipath component being considered. They are some of the important design parameters for adaptive MIMO systems. The results obtained from this study can be used to dynamically adapt the parameters of a MIMO system to the changing channel conditions in order to maintain highest level performances at all times.

References