Polarisation-sensitive array in blind MIMO CDMA system

J.W.P. Ng and A. Manikas

A blind near-far resistant MIMO array receiver employing diversely polarised array is proposed for asynchronous multipath DS-CDMA systems. By means of polarisation multiplexing, the proposed MIMO system is applicable in (i) data rate, (ii) diversity, or (iii) combinatorial maximisation schemes, without exhausting the limited spreading codes available.

Introduction: Typical MIMO works frequently assume independent multiple antenna systems, which are not sensitive to the signal’s polarisation. This work, however, proposes multiple antenna transmission, and diversely-polarised antenna-array reception in which a number of polarisation-sensitive sensors form an array system of a given geometry. In fact, it has been shown in [1] that the polarisation information inherent in the received signal, which is normally treated as polarisation fading, can be exploited to enhance the receiver’s detection capability and improve its estimation accuracy and resolution. Furthermore, besides the spatial multiplexing technique commonly employed in most MIMO research, polarisation multiplexing can also be introduced to provide additional channel capacity. For instance, by utilising the three orthogonal polarisation states offered by a tri-pole sensor for polarisation multiplexing, the data rate of the system can be tripled effectively [2]. Not only that, additional domain diversity in the form of polarisation diversity can now be attained, instead of only spatial diversity being considered in existing MIMO systems. Such diversity has been demonstrated in [3] where the same information symbol is transmitted via two orthogonal transverse fields, with each being spread by a distinct code sequence. In view of all these advantages, in this Letter we propose the use of diversely-polarised antenna-array technology in the blind asynchronous MIMO system, in which a combinatorial scheme incorporating both the data rate and diversity maximisation schemes can be implemented.

System model: Consider M asynchronous DS-CDMA users in a MIMO array system, with every user having Nc antenna elements, each capable of transmitting via P orthogonal polarisation states. The mode of transmission can be implemented in three ways. If Nc = 1, the scheme can take on either the data rate maximisation scheme (scheme 1) or the diversity maximisation scheme (scheme 2). The former scheme is performed by demultiplexing a high bit-rate input signal source into P data streams, and send simultaneously using different polarisation states. The latter scheme, on the other hand, sends P copies of the same input signal source over each of the polarisation states to maximise the diversity advantages in fading channels. However if Nc ≠ 1, a combinatorial scheme (scheme 3) can be employed; the high bit-rate input signal source is first duplicated into Nc data streams, and each later demultiplexed into P substreams and transmitted via the different polarisation states. In each of the above three schemes, a unique spreading code of length Nc is assigned to each user to be applied across its transmitting elements. Suppose the signal transmitted with the orth polarisation state the jth antenna element of the ith user arrives at the receiver, employing an array of Nc polarisation-sensitive sensors, via Kijo multipaths. By denoting its previous, current and next differential encoded data symbol as a[j,n] = [a[j-1], a[j], a[j+1]], the discretised received signal vector, incorporating inter-symbol interference (ISI), multiple-access interference (MAI), and co-code interference, can hence be expressed explicitly as follows:

\[ \hat{y}[n] = M \sum_{j=1}^{Nc} P \sum_{i=1}^{N} H_{ij} a[i,j] + \hat{d}[n] \]  

where \( \hat{d}[n] \) is the sampled complex white Gaussian noise vector, and \( H_{ij} = \{ h_{ij0} \} \) the complex path’s coefficient, and \( h_{ij0} = \{ h_{ij0} \} \) comprises 2Nc × 2N time-shift (or upshift) matrix, \( H_{ij0} = [h_{ij0}, h_{ij0}, \ldots, h_{ij0}] \) with \( h_{ij0} \) being the polar-STAR manifold vector, encompassing its path’s delay, arriving angle and state of polarisation, as described in (11) of [1].

Channel estimation and reception: By applying the PADE algorithm described in [1], the polar-STAR manifold vector of the jth user can be reconstructed based on the estimated polarisation-space-time channel parameters to obtain \( \hat{H}_{ij} = \{ \hat{h}_{ij0}, \hat{h}_{ij0}, \ldots, \hat{h}_{ij0} \} \), where \( \hat{H}_{ij} = [\hat{h}_{ij0}, \hat{h}_{ij0}, \ldots, \hat{h}_{ij0}] \) in which \( \hat{h}_{ij0} \) is the estimated composite channel parameters and \( \hat{H}_{ij0} \) is the composite matrix \( \hat{H}_{ij0} \) with the exclusion of the desired 7th user’s matrix \( \hat{H}_{ij0} \).

If scheme 2 is employed in the system, the filter bank output can be simply combined to realise the nth symbol decision statistic, i.e.

\[ \hat{d}[n] = w[n] \cdot \hat{y}[n] \]  

where \( w[n] \) is the combining weight vector obtained using the principal eigenvector of the autocorrelation matrix of (2).

However, for the other two schemes, the estimated paths need to be segregated according to their polarisation state. Taking each state \( o \in \{1, 2, \ldots, P\} \) as the reference point, the polarimetric distribution of the estimated paths can be evaluated as

\[ \delta_{DP} = \arccos \left( \frac{\cos(2\gamma_{o}) + \cos(2\gamma_{D_{P}})}{2} \right) \]  

where \( 0 \leq \delta_{DP} \leq \pi \) is the path angular distance with respect to the reference point on the Poincaré sphere. If their distances fall within a pre-specified polarimetric decision region (i.e. \( \delta_{DP} \leq \delta_{th} \)), they are grouped together under the oth polarisation state. This can then be reflected in the construction of the filter by arranging the polar-STAR manifold vectors within the matrix \( \hat{H}_{ij0} \) in a segmented manner with each segment representing each polarisation state. Each of the P segments of the filter bank outputs can then be combined using (3) and subsequently multiplexed together to realise the high bit rate data stream.

Performance analysis: Consider a uniform linear \( Nc = 5 \) elements crossed-dipole array (of half-wavelength spacing) with \( M = 3 \) co-channel users utilising a combinatorial transmission scheme. Each user is assigned a unique Gold sequence of length \( Nc = 31 \) to be shared across \( Nc = 2 \) antenna elements with each capable of transmitting \( P = 2 \) orthogonal polarisation states: left-hand circular (LHC) and right-hand circular (RHC). Let us take user 1 as the desired user with an input SNR of 10 dB, while the other two interferers each consti-
tuting an interference ratio of 10 dB (i.e. near-far problem). All three users have eight multipaths each and the array collects 150 data symbols for processing data symbols.

![Diagram](image1)

**Fig. 2** Prespecified polarimetric region $\zeta$ on Poincaré sphere

The channel parameters of all eight multipaths due to the desired user are estimated by applying the PADE algorithm to obtain the space-time spectrum plot, as shown in Fig. 1. Now since there are only two polarisation states, the pre-specified polarimetric region can be set at $\zeta = \pi/2$ with respect to the LHC point so that the upper hemisphere of the Poincaré sphere is attributed to the LHC state, while the lower is attributed to the RHC state, as illustrated in Fig. 2. Table 1 shows the polarimetric distribution of all the estimated multipaths. The proposed receiver's signal constellation is then compared with its equivalent space-time-polar decorrelating detector and 3D RAKE receiver, with the latter two assuming full knowledge of the channel. It is thus evident from Fig. 3 that the proposed blind receiver performs just as well as the decorrelating detector, while the RAKE receiver is overwhelmed with interference.

**Table 1**: Multipath polarimetric distribution of desired user $i = 1$

<table>
<thead>
<tr>
<th>Path $[(j, k, o)]$</th>
<th>$(1, 1, 1)$</th>
<th>$(1, 2, 1)$</th>
<th>$(1, 3, 1)$</th>
<th>$(1, 1, 2)$</th>
<th>$(1, 2, 2)$</th>
<th>$(2, 1, 1)$</th>
<th>$(2, 1, 2)$</th>
<th>$(2, 2, 2)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta_{\text{d}}$</td>
<td>13.9°</td>
<td>21.5°</td>
<td>0.8°</td>
<td>143.4°</td>
<td>151.7°</td>
<td>27.8°</td>
<td>165.3°</td>
<td>177.6°</td>
</tr>
</tbody>
</table>

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**References**