Combining beam forming and space time coding in macrocell multiuser scenarios

Systems with multiple antenna elements at the transmitter and receiver have received great attention because all the advantages they offer. Several gains may be obtained from the use of multiple antenna elements, mainly diversity, multiplexing and array gain. Hence recently, there have been huge research efforts on the design of schemes that allow the proper combination of several of these techniques in order to extract the maximum total gain possible of a multiantenna system, specially in more realistic scenarios and when there are varying channel conditions. Some results have already been obtained in this sense, however there are still many areas and topics to solve, specially in the Multiuser (MU) environment, where the Downlink (also called Broadcast Channel) increase the complexity of the analysis in order to derive proper implementable schemes.

Previous works and advances have been made mainly at the Single User (SU) environment. An approach that has been extensively studied considers a system with schemes that exploit channel knowledge at the transmitter. These systems depend on several aspects namely the nature of the channel knowledge (full or partial), the type of Space Time Code (STC) used and its receiver structure, and the Performance Criterion to optimize (mainly to Maximize the Capacity or to Minimize the Error Probability). In this thesis we focused on this approach assuming partial channel knowledge at the transmitter (particularly the perfect Transmit Covariance Matrix at each tap delay), we chose as performance criterion the Minimization of the Error Probability, our interest is focused on Space Time Block Coding (STBC) because of its practical implementation, and perfect Channel State Information at the Receiver (CSIRx) hence assuming a Maximum Likelihood (ML)receiver. The scheme proposed is based on the Lineal Pre-filtering architecture, where the coded signal is multiplied by a prefiltering matrix that can also be seen as a Beamforming (BF). There are several previous works that have been proposed for the SU case, for instance combining Spatial Multiplexing (SM) techniques with BF, or Spatial Diversity (SD) techniques with BF, or all of them. However, as far as we know, none of the proposed schemes takes into account all the aspects we included in our analysis, i.e. some previous works were designed with perfect Channel State Information at the Transmitter (CSITx), or with different STC, or with simplified channel models (non including simultaneously spatial correlation, frequency selectivity and rank degeneracy).

Also, many of the proposals that apply to frequency selective channels rely on some special technology, this is the case of Layered Steered Space-Time Spreading (LSSTS) system that com- bines SM, BF and Space-Time Spreading (STS) but only applies in Multicarrier Direct Sequence Code Division Multiple Access system (MCDS-CDMA) systems; it is also the case of other pro- posals that combine some or all the previously mentioned spatio-temporal techniques and rely on Orthogonal Frequency Division Multiplexing (OFDM). Although this assumptions may simplified the analysis for frequency selective channels (using an equivalent model composed of multiple par- allel flat fading channels), it may have some disadvantages, e.g. MCDS-CDMA would imply a significant increase of the bandwidth (because of the use of pseudo-noise sequences with a period of chip much lower than the period of symbol), in the case of OFDM it is known that if the guard time of the frame is lower than the excess delay of the channel the effects of frequency selectivity may still be suffered by the system. Other works that do not rely on specific technologies for frequency selective channels were based on different performance criteria or these works obtained different schemes. Additionally, most of the works assumed very simplified channel models.

In this thesis we propose a novel method to fully exploit the diversity gain of a system with multiple antenna elements at the transmitter and receiver, for the Downlink (DL) of a Macrocell Scenario, considering a channel with frequency selectivity and spatial correlation. First a SU case was derived, where we proposed a scheme that consists of an Eigenbeamformer, a Power Loading

Algorithm, an Orthogonal Space Time Block Coding (OSTBC) and a Pre-delayer, which combined together extract the maximum diversity order of the system including spatial and multipath diver- sity. The only information required at the transmitter is the Transmit Covariance Matrix at each delay tap. Ideal CSIRx is assumed. Through the Moment Generating Function Approach (MGF) approach, a Performance Criterion based on the Symbol Error Rate (SER) (which is probed to be equivalent to a Performance Criterion based on the Pairwise Error Probability (PEP)) is de- rived for typical modulations including M-ary Amplitude Modulation (M-AM), M-ary Phase Shift Keying Modulation (M-PSK) and M-ary Quadrature Amplitude Modulation (M-QAM), obtaining tight analytical bounds. In order to analyze in detail the performance of the system in a more real- istic environment, a geometrically based stochastic channel model was used allowing to study the impact of parameters as the presence of line of sight and/or single scattering, radio of each cluster, number of scatterers and number of antenna elements. The proposed scheme is then extended to the MU case, resulting in a straightforward method to apply the technique to an environment with multiple users. This proposal is based on the STS technique adapted to a STBC. It has some limitations that are described in this report.

Finally, another technique explored during the thesis is also presented, which combines Beam- forming with Power Control algorithms and a very simple coding method. Extensive simulation campaigns with the derived algorithms were performed, the most important results are presented and discussed in this report.

In section 3 we present a complete state of the art of Spatio Temporal Systems that combine different techniques in order to fully exploit their gains, the problems that have been identified and previous results already derived.

In section 4 we present the system model derived for the SU case, also we derive the Performance Criterion based on the SER (which we probed to be equivalent to the PEP criterion), find its solution and thus propose a proper transmission scheme. We also calculate the exact SER of the system proposed in order to study the performance of the system. Simulation and analytical results are then presented and discussed taking into account different physical parameters of the channel. Mathematical developments and demonstrations are included on appendixes, as well as the description and other results of the geometrically based stochastic channel model used to evaluate the performance of the system.

In section 5, we present the extended version of the previous proposal applied to a MU scenario, this proposal based on the STS technique allows to directly extend the results already obtained for the SU case to a MU environment. Additionally in this chapter, results obtained through another technique developed during the thesis are presented. The latter approach combines Power Control algorithms with Beamforming and a very simple temporal coding technique, which allows to improve the performance of the system in a Multiuser Multiantenna environment in a typical macrocell channel. Extensive simulation campaigns were executed in this part of the thesis, the main results are included and discussed in this report.