Abstract: This contribution investigates the combination of MIMO and advanced iterative receiver to have the WCDMA radio interface evolved toward higher spectral efficiency. We proposed the design of spatial Modulation and Coding Schemes (MCSs) built from ST-BICM with Linear Precoding. From an information theory point of view, these spatial MCSs are potentially capacity achieving but put high stakes on the receiver complexity. It is a major contribution to propose an efficient low-complexity MMSE-Based iterative receiver architecture to decode such schemes.

Introduction

Research context

Any communication system managing the multiple access of users on the same channel through the attribution of specific spreading codes (CDMA) is limited in capacity by the interference between users (Multiple User Interference or MUI). Within the framework of this contribution, we consider a transmission on a channel likely to generate other sources of interference such as Multiple Antenna Interference (MAI) and InterSymbol Interference (ISI) or InterChip Interference (ICI). In reception, all those interferences are added and make particularly delicate the problem of the recovery of the useful information.

The precursory work carried out by S. Verdu in the 80s [VER-86] clearly revealed the interest to exploit the structural properties of those distinct sources of interference in order to improve the performance given a fixed number of users per chip (also called "load") or to improve the load for a given fixed performance. It paved the way to Multiple User Detection (MUD). Many types of linear multiple user detectors were studied, able to support a more or less high loads. In theory, the maximum supportable load conditioned by the receiver type can be evaluated analytically in the asymptotic regime [POO-97] [ZHA-01]. Past investigations highlight that the performance of detectors, based on Zero-Forcing (ZF) or Minimum Mean Square Error (MMSE) criteria remains much lower than the one a Maximum A Posteriori (MAP) detector would provide [VER-99]. On the contrary, the class of non-linear detectors built on the idea of an iterative interference cancellation (in MMSE sense) embedded within the decision process offers an excellent compromise between performance and complexity [CHA-01]. Such non-linear MMSE-based detectors deliver decisions on the transmitted modulated data whose reliability increases in a monotonous way at each new iteration. Another remarkable point is that they can be easily and naturally combined with the hard or soft decisions delivered by the channel decoder, thus carrying out detection and decoding of the data in a disjoint iterative way (see, for example, [BOU-02] and the references therein, for a unifying framework on that topic).

When a recursive strategy is chosen at the receiver, the only option for lowering the computational load consists in simplifying to the maximum the treatments by iteration. As long as some kind of orthogonality exists between the various users at the transmitter, an attractive low-complexity approach is to restore it at the chip level before any attempt of MUD. In that light, MUD (following chip equalization) comes down to a bench of simple adapted filters to each user. This approach, developed in [LEN-00] for a non-overloaded CDMA communication model transmitted on a SISO frequency selective channel, proves to be very efficient when, for example, an aperiodic spreading is used.
This contribution...

enlarges the framework of the reference [LEN-00] by considering a communication model of overloaded CDMA transmitted on a MIMO frequency selective channel. This ambitious scenario lays the groundwork for proposing spatial Modulation and Coding Schemes (MCS) for the WCDMA High Speed Downlink Packet Access (HSDPA) evolution that are both spectrally and power efficient while ensuring the requirement of backward compatibility in the existing allocated UMTS bands. On the other hand, the level of interference is such as the resort to non-linear MMSE-based turbo-receivers proves to be essential in reception. We chose to make our spatial MCS from a potentially capacity achieving transmit scheme known as Space-Time (ST) Bit Interleaved Coded Modulation (BICM) with linear precoding, which potentially involves MUI+MAI+ISI interference at the receiver side. Our transmission philosophy conflicts conceptually with the one followed in [RIM-96] [VAR-97]. Contrary to the transmission strategy known as Successive Interference Cancellation with Per Antenna Rate Control Scheme (SIC-PARC) [ABE-04], only one CQI is needed to identify the spatial MCS to be transmitted. Moreover, our receiver design does not postulate the use of Shannon-like Gaussian codes. Indeed, we believe that the error propagation induced by real-world code in SIC-PARC makes our approach much more effective under the assumption of a well-designed low-complexity turbo-receiver.

Receiver Architecture

The receiver architecture is shown on Fig. 1, for complexity reason we chose a disjoint iterative MMSE receiver. First, the MAI+ISI are treated by a chip-based MMSE equalizer preceded by an interference (regenerated from the turbo-decoder output) subtraction. In a second step if overloading is used, the residual MUI is treated similarly in an MMSE interference cancellation sense.

Numerical Results

Independent per-antenna precoding for HSDPA evolution

Without laying claim to any kind of optimization attempt, we considered simple Walsh Hadamard rotations as precoding (or spreading) matrices. Other assumptions retained for simulations are essentially motivated by the compatibility with existing 3GPP standards with strong emphasis on HSDPA evolution. The spreading factor is fixed to N=16. Spreading is carried out independently per antenna. An overall distinct scrambling sequence is applied on each antenna, making the symbol-to-symbol precoding/scrambling matrix aperiodic. This motivates a disjoint Wiener approach at the receiver side. We chose the PCCC code C₀ of the 3GPP standards based on two rate-1/2 8-state Recursive Systematic Convolutional (RSC) codes, with generator polynomials (1,13₁₈/15₁₈). Interleaving and puncturing do not exactly mimic the standard, however. The interleaving size or uncoded block size has been chosen equal to K₀=4608 (close to the maximum allowed by the standard, i.e., 5114). The MIMO channel comprises T=2 transmit and R=2 receive antennas. It is worthy noting that a higher number of receive and transmit antennas would help our sub-optimal MMSE-based turbo-receiver (The SINR at the output of the MMSE filter becomes more and more Gaussian) and would make the design of spatial MCSs easier. We limit ourselves to that configuration on purpose for practical considerations, i.e., more than 2 receive antennas at the mobile is difficult to implement. An uncorrelated MIMO channel model is assumed, each link following a multipath profile similar to Vehicular A. Furthermore, we assumed that each of the six path components have delay of integer multiple of Tc, where Tc=0.26µs denotes the chip duration of WCDMA signal. In our proposed scheduling, the BP joint decoder does not iterate within the turbo-decoder. On the contrary, it propagates messages after one single pass of both constituent decoders, in order not to introduce isolated iterative loops in the factor graph. In all simulations, we plot the MFB as a compelling benchmark to measure the turbo-receiver efficiency at fixed MCS. As shown, the MFB coincides with the GAD bound, for this particular class of non-linear receivers. The GAD bound is itself simulated as follows: a genie cancels perfectly all sources of interference and the resulting signal is sent to the turbo-decoder. On
the basis of this ideal observation statistics, the latter performs 5 iterations. We also plot the outage capacity as an absolute benchmark to measure the power efficiency of proposed spatial MCSs.

**Full-load per-antenna precoding**

In this simulation part, we propose three spatial MCSs based on a rate-1/2 PCCC (after puncturing) and QPSK, QAM-16 and QAM-64 constellations. The number of signal components (or users) per antenna is $K_1=K_2=16$. The resulting load per antenna, i.e., the ratio (K/N per antenna, K the number of codes and N the spreading factor), is always 100%. Hence, no overloading is used for these MCSs. As a result, these 3 MCSs reach spectral efficiency $\eta=2$ bpcu, 4 bpcu and 6 bpcu respectively. Our receiver architecture is based on an iterative MMSE chip equalizer using a sliding window with length $L_{swc}=21$. No MUI detection algorithm is required in this particular scenario. As stated in the introduction, our goal is to propose spatial MCSs both spectrally efficient and power efficient for a given BLER. BLER $10^{-2}$ is usually considered sufficient when a retransmission protocol is in place. In all figures, we observe that 5 iterations are sufficient to reach the optimal performance. No significant improvement is achieved with subsequent iterations. Fig.2 shows that our QPSK spatial MCS is within 3.5 dB from the outage capacity and 1.3 dB away from the MFB. When using a higher constellation order, these discrepancies increase as expected. This can be observed on Fig. 3 which shows that our QAM-16 spatial MCS is within 5.5 dB from the outage and 4 dB from the MFB at $10^{-2}$ BLER. Similarly, Fig. 4 shows that our QAM-64 scheme is 6.5 dB from the outage and 6 dB from the MFB at $10^{-2}$ BLER.

**Per-antenna overloading**

The overloading concept gives us some additional degrees of freedom to design efficient spatial MCSs. However, we witnessed that, for this MIMO particular configuration, and given the highly frequency selective channel chosen, our receiver is not very robust to per-antenna overloading. Indeed, a per-antenna overloading of 125% (i.e., $K_1=K_2=20$) for QPSK entails a performance loss of nearly 3.0 dB at $10^{-2}$ BLER compare to the full load case (Fig. 6). Only per-antenna loads of 112.5% (i.e., $K_1=K_2=18$) seem acceptable in terms of performance degradation (1.0 dB loss), see Fig. 5 and Fig. 7.

**References**

Figures

Figure 1: Receiver Architecture

Figure 2: Performance of QPSK spatial MCS, 100% load per antenna, n=2bpcu
Figure 3: Performance of QAM-16 spatial MCS, 100% load per antenna, n=4bpcu

Figure 4: Performance of QAM-64 spatial MCS, 100% load per antenna, n=6bpcu

Figure 5: Performance of QPSK spatial MCS, 112.5% load per antenna, n=2.25bpcu
Figure 6: Performance of QPSK spatial MCS, 125% load per antenna, n=2.5bpcu

Figure 7: Performance of QAM-16 spatial MCS, 112.5% load per antenna, n=4.5bpcu