Interleave Division Multiple Access for Broadband Wireless Communications

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In modern wireless communications, Code Division Multiple Access (CDMA) and its family technologies are widely used as technical standards. However, with the rapid growth of users, the system user capacity of CDMA is now being approached due to multiple access interference (MAI) as well as inter-symbol interference (ISI). With the invention of turbo codes, the significant progress on mitigating MAI and ISI by iterative multiuser-detection (MUD) has been made. Since the achievability of the multiple access channel (MAC) capacity region has been theoretically proven, many researches have tried to design the practical systems that can achieve the performance as close to the capacity region as possible. The superiority of CDMA systems with the entire bandwidth-expansion factor being allocated only for error correction coding by using very low rate code, where no spreading is used, is well known as a fundamental concept of communication theory. To make effective use of this theoretical background, a CDMA technique with chip-level interleaving is proposed, which was then reformulated and introduced to be the concept of interleave division multiple access (IDMA).

It is well known that the smaller the rate of the code used, the lower the signal-to-interference-plus-noise power ratio (SINR) required to achieve arbitrarily low message error rate. In this sense, IDMA has a higher potential for accommodating large number of users than CDMA techniques that encodes the information sequence by a channel code first, and then spreads the coded sequence bit-by-bit. This is because spreading is equivalent to repetition coding, which only achieves a gain in signal-to-noise power ratio (SNR), and the gain is in proportion to the spreading factor. However, designing such low rate and powerful, near-capacity achieving codes that is suitable for IDMA and can be decoded without imposing heavy computational complexity, has long been a bottleneck. A quantitative comparison between an intermediate solution (which is a combined use of a convolutional code and a low rate repetition code) and conventional CDMA (where error correction coding and spreading are independently performed) is made to reveal the advantages of IDMA. Recently, it has been shown that IDMA with non-Gray (natural) mapping rules achieves better performance than with the Gray mapping, and such tendency is verified by the the *extrinsic* information transfer (EXIT) analysis. However, the bit error rate (BER) curves exhibits an error-floor because of not well matched EXIT curves.

Quite recently, a very excellent idea has been proposed to describe a technique that jointly optimize the mapping labeling rule and code parameters, resulting in very close matching of EXIT curves between the demapper and the decoder. The technique, EXIT-constrained binary switching algorithm (EBSA), uses extended mapping (EM) for modulation, which maps multiple labeling patterns to a single constellation point, and the code parameters are determined by using linear programming (LP) for code design; by repeating the code and labeling pattern design alternatively, very close matching of the EXIT curves can be achieved. The EBSA technique was applied to bit interleaved coded modulation with iterative detection (BICM-ID) with EM, where single parity check (SPC) and irregular repetition (IrR) code are used as the channel code. EBSA is found to be surprisingly powerful and flexible in jointly optimizing the parameters; it is shown that the near-capacity BER performances can be achieved, although the BICM-ID decoder requires computational complexity of only roughly 1/4 of the turbo code. Furthermore, error-floor is eliminated (or at least reduce it to a value region below $10^{-6} - 10^{-5}$ of BER). Inspired by the powerfulness and the high flexibility of the EBSA technique, the research on whether or not its near-capacity performance using BICM-ID and very low rate SPC-IrR codes is still effective when it is applied for IDMA has been invoked; the research interest includes BICM-ID-based IDMA systems design, performances analysis in the different type of channels, and verification of the sensitivity to frame-asynchronism.

This thesis investigates an up-link multiple access technique with IDMA of which the crucial requirement is the proper operability at a very low SINR value range. The primary objectives of this thesis are twofold: (1) to design and evaluate IDMA systems based on BICM-ID and optimization of the BICM-ID system using EBSA over additive white Gaussian noise (AWGN) channels, (2) to further jointly utilize a frequency domain soft-interference cancelation minimum mean-square error (FD-SC-MMSE) turbo equalization in frequency selective fading channels. Particularly, in order to further improve the performance of the system and verify the superiority of the proposed system, the impact of the power allocation on the convergence and the MAC rate region, robustness against the asynchronism and the impact of detection ordering are also investigated.

First of all, this thesis focuses on the IDMA system design that requires proper operability at a very low SINR range in AWGN channels. The achievability of near-capacity performance of BICM-ID, using very low rate SPC-IrR codes at a very low SINR range, is demonstrated. The technique is hence effective in achieving excellent performance when it is applied for IDMA; then, a very simple MUD technique for the SPC-IrR BICM-ID IDMA is proposed, which does not require heavy per-iteration computational burden; after that, the impacts of power allocation on the convergence property of MUD as well as on the rate region is analyzed by using EXIT chart; moreover, performance sensitivity to frame-asynchronism of the proposed system is investigated. The SPC-IrR code parameters and the modulation labeling patterns are optimized by using the EBSA technique at a very low SINR range. Simulation results show that the proposed technique can achieve excellent near-capacity performance with the BER curves exhibiting very sharp threshold, which significantly influences the convergence property of MUD. Then, this thesis presents results of the multiple access rate region analysis in the cases of equal and unequal power allocation. The results of the rate region analysis for a counterpart technique is also presented. The results of the MAC rate region analysis show that our proposed technique outperforms the counterpart technique. Furthermore, the results of series simulations indicates the robustness of the proposed IDMA technique against frame-asynchronism.

This thesis then aims to combine turbo equalization and BICM-ID-based IDMA techniques over frequency selective fading channels. The codes parameters and modulation labeling patterns are also optimized by EBSA at a very low SNR range. FD-SC-MMSE turbo equalization is used together with IDMA signal detection to detect all the simultaneous users. Moreover, a detection ordering (DO) technique is proposed to improve the efficiency of the detection scheme. Simulation results show that the proposed technique can eliminate the influences of both ISI and MAI, due to, respectively, the fading frequency selectivity and the channel sharing with other simultaneous users, and achieve the excellent frame error rate (FER) performance in the cases of single, 8 and 10 simultaneous users although the user number is larger than its equivalent spreading factor. The comparison of the performances between the system with and without DO shows that significant performance improvement with DO technique can be achieved.