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Irregular Repetition Code-Based Bit-Interleaved Coded Modulation with Iterative Detection (BICM-ID) Using Extended Mapping in Broadband Wireless Communications with Turbo Equalization

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Digital communication systems have become a core part of our daily life. The technical challenge is to enable high data transmission rates with high power and bandwidth efficiencies. Furthermore, the aims in design of communication systems include manageable computational complexity and low end-to-end latency. The theoretical limits of data transmission were derived by Shannon. His landmark paper published in 1948 shows that information can be transmitted with an arbitrary low bit error rate (BER) as long as the data transmission rate is below the so-called channel capacity. To approach the capacity and to achieve high bandwidth efficiency, high order modulation and powerful channel coding schemes are required. Joint design of coding and modulation to optimize the performance of digital transmission schemes was proposed later by Massey in 1974, of which technical category is referred to as coded modulation. The breakthrough towards capacity approaching channel code design is the idea of iterative decoding of concatenated codes, which is so-called turbo coding technique. The idea of iterative decoding has been extended flexibly to more general cases, referred to as turbo principle, which can be applied to the receiver of a communication system with serial and parallel concatenated components. Research topics on bit-interleaved coded modulation with iterative detection (BICM-ID) fall into the category of joint design of coding and modulation, cross physical-and-medium access (PHY-and-MAC) layer optimization, with the aim of achieving close-Shannon limit performance, which is also the goal of this thesis.

Iterative detection and decoding take place at the receiver, where extrinsic log likelihood ratio (LLR) obtained by the maximum *a* posteriori probability (MAP) algorithm is exchanged between demapper and decoder, according to the standard turbo principle. Since in principle, BICM-ID is a serially concatenated system, analyzing its performances can rely on the area property of the extrinsic information transfer (EXIT) chart. Therefore, the transmission link design based on BICM-ID falls into the issue of matching between the demapper and the decoder EXIT curves. Various efforts have been made in the seek of better matching between the two curves for minimizing the gap while still keeping the convergence tunnel open, aiming, without requiring heavy decoding complexity, at achieving lower threshold signal-to-noise power ratio SNR and BER floor.

In this thesis, a new BICM-ID technique, extended mapping (EM) and frequency domain soft cancellation minimum mean square (FD SC MMSE) equalization, jointly designed with check node assisted irregular repetition code, is proposed to optimize the performance of BICM-ID transmission systems for broadband single carrier signaling over multipath propagation channels. This approach is, first of all, investigated in additive white Gaussian noise (AWGN) channel to better observe its properties, and further extended to frequency selective fading channels with the aim of making the outage based transmission feasible in practical mobile communications systems.

It has been believed that for BICM-ID a combination of Gray mapping and Turbo code or low-density parity-check (LDPC) codes achieves the best performance, compared with other combinations. However, other approaches towards achieving good matching between the two EXIT curves are also proposed by literatures, such as anti-Gray mapping with even simpler codes convolutional codes, with which it is still possible to achieve BER pinch-off. Another idea that can provide us with design flexibility is EM. With EM the label length can be adjusted while staying on the same constellation diagram. This enables us to adjust the spectral efficiency not only by changing the rate of the channel code, but also changing the labeling length of the used mapping scheme. One of the major advantages of EM, instead of using higher order constellation diagrams, is that the system hardware can be optimized only for the one single constellation diagram. In this thesis, it is shown that turbo cliff happens at a value range of SNR, $1 \sim 2$dB to the Shannon limit when combining EM and repetition code. In order to further enhance the code design flexibility and reduce the BER floor, the check node and irregular degree allocation are introduced to the repetition code based structure. It is shown that the EXIT function of the demapper for EM is well matched to the very simple coding technique, check node assisted irregular repetition code. To achieve high power and spectral efficiencies, design parameters with the check node assisted irregular repetition code are optimized to minimize the area between demapper and channel decoder EXIT functions while without having them intersect before reaching a point close to *mutual information* (MI)=1. The structure of this code is extremely simple and the decoding complexity is low. There is no iteration needed in the decoder itself. The turbo cliff and BER floor can be flexibly controlled so that they occur within a desired SNR value range, by carefully choosing the irregular degree allocations. Moreover, doping modulation helps realize very low rate code design.

In fading channels with frequency selectivity, turbo equalization has been recognized as being one of the most efficient techniques that can remove the inter-symbol interference (ISI) in broadband single carrier signaling. A sub-optimal turbo equalization technique, FD SC MMSE filtering, can achieve asymptotically optimal performance without requiring heavy computational burden. However, if Gray mapping is used, FD SC MMSE's EXIT curves vary quite largely due to the fading variation and hence if the code parameters are fixed, BER performance vary significantly, according to the intersection point of the demapper and decoder's EXIT curves. Since the EXIT curves of the FD SC MMSE equalizer spreads widely, according to the channel realizations, the intersection between the EXIT functions of equalizer and a convolutional code happens in a large range of the MI values. This implies that sharp turbo cliff is unexpected with this combination (=Gray mapping and convolutional codes) which has been heavily investigated since the advent of the turbo equalization concept. By using EM, the variations of EXIT curves can be compressed and therefore by combining EM with irregular repetition code, the variation of BER is expected to be smaller. With this statistical property of the EXIT functions, it is made possible to design the BICM-ID chain such that with the majority of the channel realizations, the turbo cliff happens, without requiring channel realization-by-realization code parameters optimization. Hence, it provides a practical solution to the outage-based transmission chain optimization. Comparing with the conventional code based technique, the performance can be, thereby, significantly improved while keeping the computational complexity almost equivalent.