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A Very Simple BICM-ID with EXIT Constraints

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Recently, wireless communications are widely used in our daily life. Examples are voice communications over cellular wireless networks, Internet connection via WiFi and etc. Those technologies are still developing towards an ultimate goal of human being, where people can communicate and access the necessary data anywhere at any time. One of the challenges is to develop a technological basis that allows for more data to be transmitted reliably over wireless communication systems at a time, so that high data rate transmission is made possible. Another emerging challenge is to realize energy efficient wireless communication systems to reduce carbon dioxide emission. Reduction of computational burden for communication system is obviously inevitable challenge. Those three challenges are related each other.

When Signal-to-Noise power Ratio (SNR) for a communication system is given, maximum code rate for channel coding which achieves arbitrary low Bit Error Rate (BER) can be derived. This theoretical limit in rate is called channel capacity; if the rate for channel coding is smaller than the channel capacity, arbitrary low BER can achieved. In addition, given the bit rate of the system, there exists a required SNR, and if it is larger than the threshold value, BER can be made arability small. This threshold in SNR is called "Shannon limit" . Approaching this channel capacity and

Shannon limit is the key element to designing the wireless communication systems with high data transmission rate and high energy efficiency.

After the publication of Shannon's channel coding theorem, a lot of effort has been made to find codes that can achieve the Shannon limit. Discovery of Turbo code, found by Berrow in 1993, was a landmark event in the history of Information theory, since the code can asymptotically achieve the Shannon limit. It is shown that Turbo code comprised of memory-4 constituency convolutional codes can achieve 0.6 dB, in SNR, to the Shannon limit. Today, Turbo code is widely used in various applications. Analysis of the extrinsic information exchange between the constituency decoders plays key role towards designing limit achieving Turbo code. This fundamental mechanism is known as the turbo principle, and it is widely used to design Shannon limit-approaching techniques based on the turbo principle.

Bit-Interleaved Coded Modulation with Iterative Detection/Decoding (BICM-ID) has been recognized as being a bandwidth efficient coded modulation and transmission scheme, of which transmitter is comprised of a concatenation of encoder and bit-to-symbol mapper separated by a bit interleaver. Iterative demapping-and-decoding takes place at the receiver, where extrinsic Log Likelihood Ratio (LLR) obtained as the result of the Maximum A posteriori Probability algorithm for demapping/decoding is forwarded to the decoder/demapper via deinterleaver/interleaver, and used as the a priori LLR for decoding/demapping, according to the standard turbo principle.

Performances of BICM-ID have to be evaluated in terms of convergence and asymptotic properties, which are represented by the threshold SNR and BER floor, respectively. In principle, since BICM-ID is a serially concatenated system, analysing its performances can rely on the area property of the EXtrinsic Information Transfer (EXIT) chart representing efficiency of the Mutual Information (MI) exchange. Therefore, the transmission link design based on BICM-ID falls into the issue of matching between the demapper and decoder EXIT curves. Various efforts have been made, seeking for better matching between the two curves for minimizing the gap while still keeping the tunnel open, aiming, without requiring heavy demapping/decoding complexity, at achieving lower threshold SNR and

BER floor.

D.Zhao et.al. proposed a yet very simple, close Shannon-limit approaching BICM-ID system. It uses very simple codes, irregular repetition and single parity check codes, combined with Extended Mapping. There are two issues which must be coped with to achieve better performance of this technique. One is that even having known that the key role played towards the optimal design of the proposed code requires optimal degree allocation for variable nodes, though, the irregular degree allocation to the node degrees were determined only empirically. Another fundamental drawback is that it still suffers from the error floor. This is simply because the demapper EXIT curve does not reach the top-right (1.0,1.0) MI point.

This thesis proposes the techniques to solve these problems. It is shown in this thesis that the problem of systematically obtaining the optimal degree allocation falls into the Linear Programming (LP) problem. With the LP technique, higher spectrum efficiency and lower BER can be expected. However, there still is a problem that error floor can not be eliminated with the LP optimization. This is because the demapper and decoder EXIT curves intersect at a point (X, Y), where $X \approx 1.0$ but $Y < 1.0$. Then, this thesis shows the technique to make the demapper curve reach the top-right (1.0,1.0) MI point by the use of partial accumulator. EXIT chart analysis confirms that the use of partial accumulator is of significant importance in the proposed system. Furthermore, only except the left-most potion, smooth matching between the demapper and decoder curve is achieved by using the partial accumulator and LP aided optimization. Furthermore, this thesis points out that with the partial accumulator, labelling pattern must be redesigned, aiming at better matching of the two EXIT curves. This is because the conventional labelling pattern was designed so that the right-most point of the demapper EXIT curve approaches the $(1.0, 1.0)$ MI point. However, the combined use of partial accumulator lifts the demapper EXIT curve up to a point close enough to the $(1.0, 1.0)$ MI point. A novel techniques, EXIT-constraint Binary Switching Algorithm (EBSA) and unbalanced labelling have been introduced in this thesis to obtain the optimal labelling pattern which takes into account the matching between the two EXIT curves as constraints for the optimization.

This thesis presents simulation using proposed techniques. Simulation results proves that the proposed technique can achieve the near-optimal performances. It is found that when the proposed LP technique is used at SNR = 0.9 dB, the spectrum efficiency is 0.95 bits/symbol, which is 0.05 bits/symol higher the the empirically designed case. However, the 0.9 dB threshold SNR where the turbo cliff happens, for 0.95bits/symbol is 1.3dB away from the Shannon limit. When the LP technique and partial accumulator is used, the spectrum efficiency is 1.076 bits/symbol, which is 0.1602 bits/symbol higher than the empirically designed case. The threshold SNR for 1.076 bits/symbol is only 0.95 dB away from the Shannon limit. Furthermore, it is found that, by using the proposed partial accumulator, BER floor can be completely eliminated. Finally, using the EBSA and unbalanced mapping, it has been shown through BER simulations that the threshold SNR is only 0.54dB away from the Shannon limit, while the required complexity is at the same level as a turbo code with only memory-2 constituency codes. If the same performance in terms of the threshold SNR as the proposed SPCCIRC-BICM-ID-EM system is required with the turbo code, memory-4 convolutional constituency codes have to be used, of which complexity is approximately 4 times the system proposed in this thesis.