Joint Source-coding, Channel-coding and Modulation schemes for AWGN and Rayleigh Fading Channels

S. X. Ng, F. Guo, J. Wang, L-L. Yang and L. Hanzo

Department of Electronics and Computer Science, University of Southampton,

Southampton SO17 1BJ, United Kingdom

{sxn,fg01r,jw02r,lh}@ecs.soton.ac.uk, http://www-mobile.ecs.soton.ac.uk

Abstract

Joint source-coding, channel-coding and modulation schemes based on Variable Length Codes (VLCs), Inphase-Quadrature phase (IQ)-interleaved Trellis Coded Modulation (TCM) and Turbo TCM (TTCM) schemes are proposed. A significant coding gain and a lower error floor are achieved without bandwidth expansion.

Introduction: Trellis Coded Modulation (TCM) [1, 2] and Turbo TCM (TTCM) [2, 3] are bandwidth efficient channel coding schemes, which were originally designed for transmission over Additive White Gaussian Noise (AWGN) channels. Set partitioning based phasor constellation labelling was used in these schemes in order to increase the minimum Euclidean distance between the encoded information bits. A symbol-based turbo interleaver and a symbol-based channel interleaver were utilised for the sake of achieving time diversity, when communicating over Rayleigh fading channels. Recently, Inphase-Quadrature phase (IQ)-interleaved TCM and TTCM schemes were proposed for transmissions over complex Rayleigh fading channels in [4], where *significant coding gains were achieved without compromising the coding gain attainable over AWGN channels.*

Lossless Variable Length Codes (VLCs) are low-complexity source compression schemes, where no codeword is allowed to constitute a prefix of another codeword. In order to improve the error-resilience of VLCs, numerous trellis-based VLC decoding techniques have been proposed, such as the joint source/channel coding scheme of [5] where the VLC decoder uses the bit-based trellis structure of [6]. Explicitly, in [5] a reversible VLC [7] was invoked as the outer code and a convolutional code was utilised as the inner code. However, the explicit knowledge of the number of VLC output bits is required for the VLC's bit-based trellis decoding, which has to be signalled to the decoder, reducing both the compression efficiency and the error resilience.

IQ-TCM/TTCM-VLC: *In order to improve the bandwidth and power efficiency of the joint source/channel coding scheme contrived in [5], in this contribution we proposed the novel concept of amalgamated source-coding, channel-coding and modulation. The performance benefits of the* *scheme will be demonstrated in the context of an IQ-TCM/TTCM-VLC scheme, which invokes IQ-TCM/TTCM coded modulation as the inner constituent code.* The VLC outer encoder outputs a variable-length bit sequence at each encoding instance. However, we fix the VLC encoder's total bit sequence length to L_{bit}, in the range of $(2048m - l_{max}) \leq (L_{bit} + L_{side}) \leq 2048m$, where m is the number of original VLC-encoded bits per TCM/TTCM coded symbol, l_{max} is the longest VLC codeword length and L_{side} is the number of bits required for conveying the side information related to the number of VLC bits/symbols per transmission burst to the VLC decoder. Furthermore, L_{dummy} number of zero-valued dummy bits are concatenated to the VLC output bit sequence such that $L_{bit} + L_{dummy} + l_{side} = 2048m$ bits. In an effort to render our investigation as realistic as possible, the side information related to the number of bits/symbols conveying the VLCs is explicitly signalled by repeating them three times for the sake of majority logic based detection and then TCM/TTCM encoded. The resultant $2048m$ number of bits representing the VLC output bits, dummy bits and side information bits are treated as input bits of the TCM/TTCM encoder, which has a coding rate of $R_{cm} = \frac{m}{m+1}$ and employs a 2^{m+1}-level modulation scheme.

The novel decoder structure of the IQ-TTCM-VLC scheme is illustrated in Figure 1, where there are three constituent decoders, each labelled with a round-bracketed number. Symbol-based and bit-based Maximum Aposteriori Probability (MAP) algorithms [2] operating in the logarithmic-domain are employed by the TCM decoders and by the VLC decoder, respectively. The notations P, S, A and E denote the logarithmic-domain probabilities of the parity information, the systematic information, the *a priori* information and the *extrinsic* information, respectively. The notations L_p, L_e and L_i denote the Logarithmic-Likelihood Ratio (LLR) of the *a posteriori*, *extrinsic* and *intrinsic* information, respectively. The probabilities or LLRs associated with one of the three constituent decoders having a label of $1 \cdots 3$ are differentiated by the super-script of $1 \cdots 3$. The logarithmic-domain symbol probabilities of the IQ-interleaved TTCM-coded symbols are computed by the demodulator based on the approach of [4]. There are 2^{m+1} probabilities associated with an $(m+1)$-bit TTCM-coded symbol, which have to be determined for the MAP decoder [2]. These probabilities are input to the TTCM MAP decoder as $[P\&S]$, which indicates the inseparable nature of the parity and systematic information [2, 3]. The *a posteriori* information of the m-bit systematic part of an $(m+1)$-bit TTCM symbol at the output of a constituent TCM decoder can be separated into two components (Section 9.4 [2] and [3]): 1) the inseparable *extrinsic* and systematic component $[E\&S]$ also refered to as the *intrinsic* component, which is generated by one of the constituent TCM decoders, and 2) the *a priori* component A, which is provided by the other constituent TCM decoder. However, in our proposed scheme the *a priori* component A comprises also the additional *extrinsic* information provided by the constituent VLC decoder, namely E^3, as we can see from Figure 1. Explicitly, $A^{(1,2)} = [E\&S]^{(2,1)} + E^3$, where the extrinsic component E^3 contributing to A^2 is the symbol-interleaved version of E^3 contributing to A^1. The *a posteriori* information of the m-bit systematic part of an $(m + 1)$-bit TTCM symbol provided by the second TCM decoder is then symbol-deinterleaved and converted to LLRs. First the side information has to be extracted. Hence, based on the side information segment of the TTCM decoded *a posteriori* LLRs, the number of dummy bits, the number of VLC output bits and the number of VLC input symbols are calculated. Then only the *a posteriori* LLRs associated with the VLC bit sequence are passed on to the VLC decoder. The *a priori* LLR of a VLC-coded bit is constituted by the sum of the *intrinsic* LLRs of both TCM decoders, which is shown in Figure 1 as $L_a^3 = L_i^1 + L_i^2$. Based on L_a^3 and on the calculated number of VLC output bits, the bit-based VLC MAP decoder computes the *a posteriori* LLR as $L_p^3 = L_e^3 + L_i^1 + L_i^2$. Only the *extrinsic* LLR L_e^3 is passed back to the TTCM decoder. The VLC decoder's extrinsic LLR L_e^3 is concatenated with the LLRs of the side information, where the latter component is represented by zeros in the LLR-domain, since the corresponding probabilities are assummed to be 0.5. Furthermore, the LLRs of the dummy zero bits are concatenated as large negative LLR values. Finally, LLR-to-symbol probability conversion is invoked for generating E^3. At the final outer iteration, a maximum likelihood sequence estimation based on L_p^3 is invoked for yielding the original uncoded information bits. A conceptually less sophisticated and less powerful solution is constituted by an IQ-TCM-VLC decoder structure, which is similar to that of Figure 1 with the simplification that the second TCM decoder is removed and the *a posteriori* information of the first TCM decoder is passed directly to the symbol-to-LLR probability converter.

Simulation results: We evaluated the performance of the proposed schemes using 16-level Quadrature Amplitude Modulation (16QAM) in the context of both the non-iterative 64-state TCM scheme [1] and that of the iterative 8-state TTCM arrangement using four decoding iterations [3]. These TCM and TTCM parameters were chosen for the sake of maintaining a similar decoding complexity [4]. The reversible VLC codes used in the simulations were adopted from [7], where the codewords are $C = \{00, 11, 010, 101, 0110\}$. In Figure 2, we show the Bit Error Ratio (BER) versus signal to noise ratio per bit, namely E_b/N_0, performance of 16QAM based IQ-TCM-VLC, TCM-

VLC, IQ-TTCM-VLC, TTCM-VLC and that of the uncoded 8-level Phase-Shift-Keying (8PSK) benchmarker when communicating over uncorrelated flat Rayleigh fading channels. The effective throughput is 3 Bits Per Symbol (BPS). As we can observe from Figure 2, the BER floor of IQ-TCM-VLC is lower than that of TCM-VLC. However, the IQ-diversity gain of IQ-TTCM-VLC diminished, when the number of outer iterations was increased.

Conclusions: *In this contribution the novel concept of amalgamated source-coding, channel-coding and modulation was proposed. The achievable performance benefits were demonstrated in the context of the novel IQ-TTCM-VLC and IQ-TCM-VLC schemes suitable for transmissions over both AWGN and flat Rayleigh fading channels. Specifically, in the case of an uncorrelated flat Rayleigh fading channel, the (IQ-)TTCM-VLC scheme employing four outer iterations attained a coding gain of* **39.2 dB** *over uncoded 8PSK at a BER of* 10^{-5}. *The proposed concept is applicable also to other combinations of VLC codes and coded modulation schemes.*

References

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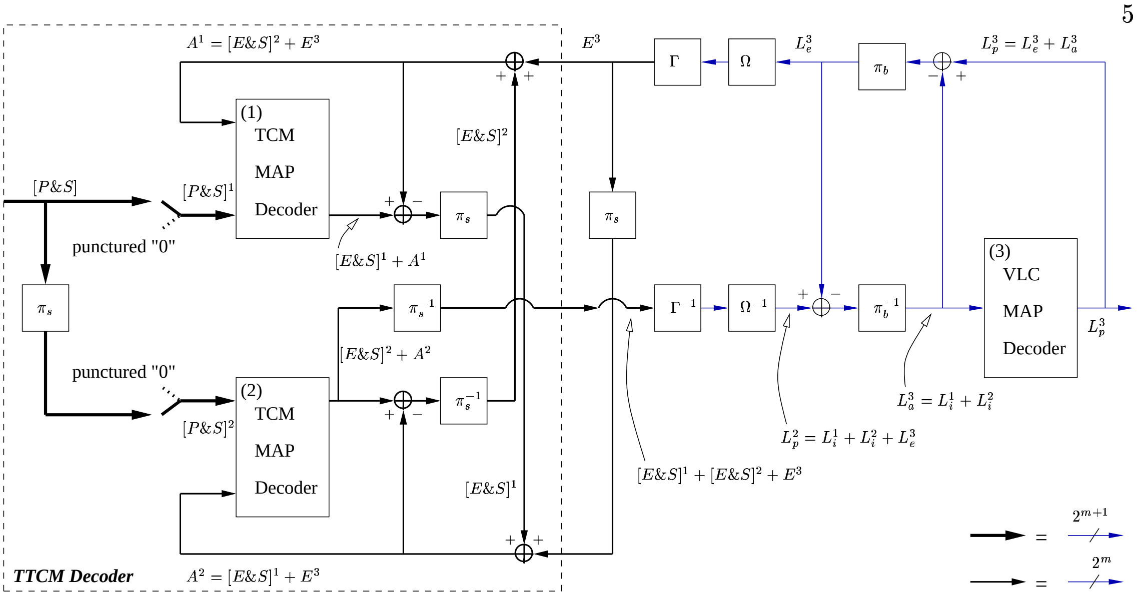

Figure 1: Block diagram of the IQ-TTCM-VLC scheme. The notations $\pi_{(s,b)}$ and $\pi_{(s,b)}^{-1}$ denote the interleaver and deinterleaver, while the subscript s or b denote the symbol-based or bit-based nature of the interleaver, respectively. Furthermore, Γ and Γ^{-1} denote LLR-to-symbol and symbol-to-LLR probability conversion, while Ω and Ω^{-1} denote the addition and deletion of the LLRs of the side information and dummy bits.

S. X. Ng, F. Guo, J. Wang, L-L. Yang and L. Hanzo are with University of Southampton.

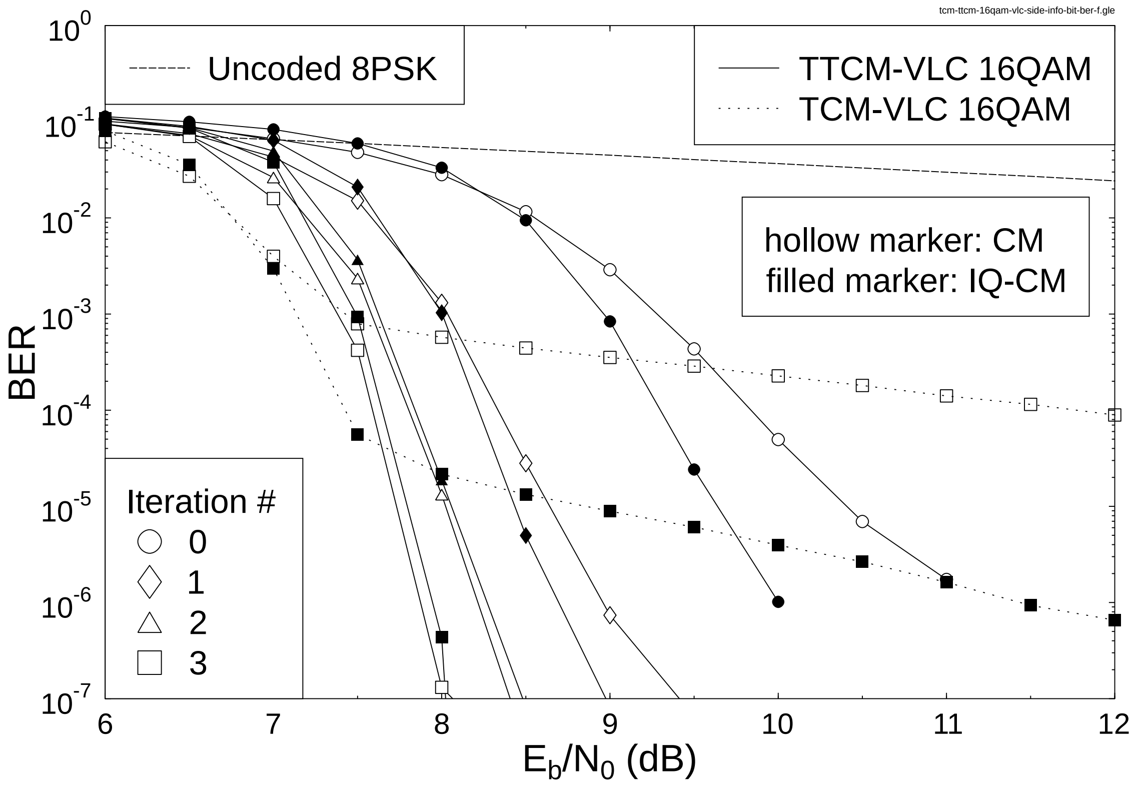

Figure 2: BER versus E_b/N_0 performance of 16QAM based IQ-TTCM-VLC, TTCM-VLC, IQ-TCM-VLC, TCM-VLC and uncoded 8PSK. All of these schemes have an effective throughput of **3 BPS.**