On the Performance of Parallel Concatenated Joint Source-Channel Coding with Variable-Length Codes

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Abstract — **A novel approach for robust source transmission is presented where variable-length code (VLC) source and convolutional channel encoding are concatenated in parallel. Simulation results show that the proposed scheme leads to a strong increase in the signal-to-noise ratio at the decoder output compared to a serial concatenation of VLCs and channel codes.**

In the considered transmission system indices I_k, $k = 1, \ldots, K$, from a finite alphabet $\mathcal{I} = \{0, 1, \ldots, 2^M - 1\}$ are obtained by scalar quantization of packetized correlated source symbols U_k. The mutual dependencies between the I_k are modeled as a first-order stationary Gauss-Markov process with transition probabilities $P(I_k = \lambda \,|\, I_{k-1} = \mu)$, $\lambda, \mu \in \mathcal{I}$. Each index $I_k = \lambda$ is then mapped to a variable-length bit vector $\mathbf{c}(\lambda)$ leading to a bitstream $\mathbf{w}$ of length N_S. In parallel, a bit-interleaved version of the binary vector $[I_1, \ldots, I_K]$ is applied to a terminated recursive systematic convolutional (RSC) channel code. Only the parity bits of each codeword are considered, which results in a length-N_C binary sequence $\mathbf{v}_p$. Then, the sequences $\mathbf{w}$ and $\mathbf{v}_p$ are multiplexed and transmitted over an AWGN channel. At the channel output the soft-bit vectors $\hat{\mathbf{w}}$ and $\hat{\mathbf{v}}_p$ are received.

In the corresponding iterative decoder one constituent decoder consists of the symbol-level soft-input soft-output (SISO) VLC source decoder from [1], which calculates a-posteriori probabilities $P(I_k = \lambda \,|\, \hat{\mathbf{w}})$ for the source indices I_k. These reliabilities are converted to L-values $L^{(S)}(i_{k,\ell}) = L_e^{(S)}(i_{k,\ell}) + L_a^{(S)}(i_{k,\ell})$ for the source index bits $i_{k,\ell} = \lambda_\ell$, $\ell = 1, \ldots, M$, where $L_a^{(S)}(i_{k,\ell})$ denotes the a-priori term. Due to the non-systematic property of the VLC the L-values $L_e^{(S)}(i_{k,\ell})$ cannot be further separated into a channel and an extrinsic term. Therefore, in contrast to turbo decoding with systematic codes where the received information bits are also applied to the second constituent decoder, here this information is provided by using $L_e^{(S)}(i_{k,\ell})$ as a-priori information for the SISO channel decoder after bit-interleaving. The feedback to the source decoder is carried out as in standard turbo decoding by sending extrinsic information $L_{\text{extr}}^{(C)}(i_{k,\ell})$. Since the VLC source decoder requires index-based a-priori information, the bit-based a-priori L-values from the channel decoder are converted to index-based probabilities $P_a(I_k = \lambda \,|\, \hat{\mathbf{v}}_p)$. After each iteration, reliability values $\tilde{P}(I_k = \lambda \,|\, \hat{\mathbf{w}}, \hat{\mathbf{v}}_p)$ emerge at the output of the source decoder, which are used in order to obtain a mean-squares estimate of the source symbol U_k.

In order to increase the performance of iterative decoding an optimization of the VLC codeword index assignments can be carried out for the proposed parallel concatenated joint source-channel coding (PCJSCC) approach in the same way as for the serially concatenated fixed-length case [2]. This is due to the fact that in the iterative decoder in both cases extrinsic information is generated for the *information* bits. In the VLC case only index permutations between codewords of equal lengths are allowed, where the index mapping function $g\colon \{0,1\}^M \to \{0,1\}^M$ is optimized such that $E\{(u_\lambda - u_\kappa)^2\}$ is maximized. Herein, u_λ denotes the quantizer reconstruction level for the undistorted source hypothesis λ, and u_κ represents the reconstruction level with the index $\kappa = g^{-1}(g(\lambda) \oplus t) \in \mathcal{I}$ where $g(\lambda) \in \mathcal{I}$ is distorted by a single bit error generated from the weight-one error pattern $t \in \{0,1\}^M$. In contrast, for the VLC-based serially concatenated JSCC approach (SCJSCC) [1] being used for comparison, it has to be considered for the mapping optimization that in the corresponding iterative decoder extrinsic information is calculated for the VLC *code*bits and not for the bits $i_{k,\ell}$.

The simulation results for both parallel and serially concatenated schemes are shown in Fig. 1 for both an optimized (suffix "Map") and an identity (natural) index mapping. The source redundancy is modeled by a strongly correlated AR(1) source process quantized with $M = 5$ bits, and both approaches use a symmetrical reversible VLC (RVLC). The parameters K, N_S, and N_C are assumed to be transmitted without errors to the decoder. The RSC codes are selected for reconstruction SNR (RSNR) maximization by an exhaustive code search over all unpunctured mother codes with code memory $\mu = 3$ and $R_C = 1/2$ based on test simulations in the desired operating range of $0\,\text{dB} \leq E_b/N_0 \leq 2\,\text{dB}$. The overall code rates R_P and R_S for PCJSCC and SCJSCC, resp., take the additional rate contributions from the residual source redundancy and the RVLC into account. Fig. 1 reveals that in the desired operating range the PCJSCC approach shows a strong RSNR gain compared to SCJSCC.

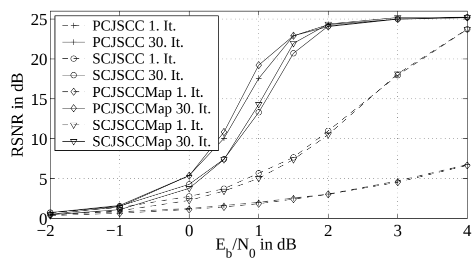

Fig. 1: Reconstruction SNR vs. E_b/N_0 ($K = 100$, $R_P \approx R_S \approx 0.3$, AR(1) source process with $a = 0.9$, $M = 5$, optimized RSC generator polynomials $(g_0, g_r)_8$: $(15, 11)_8$ for SCJSCC, $(12, 11)_8$ for PCJSCC)

Acknowledgments

The author would like to thank Ragnar Thobaben for contributing parts of the simulation software.

References

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