Turbo trellis coded modulation for transform domain distributed video coding

J.L. Martinez, W.A.R.J. Weerakkody, W.A.C. Fernando, F. Quiles and A.M. Kondoz

A transform domain distributed video coding (DVC) codec is proposed using turbo trellis coded modulation (TTCM). TTCM symbols are generated at the DVC decoder using the side information and the parity bits received from the DVC encoder. These generated symbols are used at the TTCM-based DVC decoder to decode the bit stream. Simulation results show that a significant rate-distortion performance gain can be achieved using the proposed codec compared to the best state-of-the art transform domain DVC codecs discussed in the literature.

Introduction: Distributed video coding (DVC) is known to be a technique used to reduce the processing complexity of the encoder, leading to a low-cost implementation, while the majority of the computations are taken over by the decoder. There are some applications that will benefit from this video coding architecture, such as wireless video surveillance, multimedia sensor networks, disposable video cameras, medical applications and mobile camera phones. The theoretical framework of DVC is based on the distributed source coding principles discussed for lossy coding by Wyner-Ziv [1]. Based on this theoretical framework, several DVC codecs have been proposed recently, both in the pixel domain and in the transform domain. Transform domain DVC codecs have shown better performance compared to the pixel domain codecs since spatial correlation is exploited at the encoder. Several transform domain architectures have been proposed [2–6]. These architectures have been developed using either DCT or DWT primarily with turbo codes. In this Letter, we propose the use of turbo trellis coded modulation (TTCM) for transform-based DVC codecs owing to its higher coding gain and its immunity to noise.

Proposed codec: TTCM is a well known channel coding technique used to optimise the bandwidth requirements while protecting the information bits by increasing the size of the symbol constellation. The aim of the work discussed in this Letter is to exploit the high coding gain and the noise immunity inherent in this technique for DVC. Fig. 1 shows the block diagram of the proposed video codec implementation in the transform domain based on TTCM coding, in contrast to turbo coding as used in common DVC codecs discussed in the literature.

Fig. 1 Proposed system

The frames for Wyner-Ziv coding are initially transform coded using integer $4 \times 4$ block based DCT, as defined in [3]. The core computations of the transform only require additions and shifts, keeping the philosophy of low-complexity encoders in DVC. As defined in [7], a scalar multiplication (part of the complete transform) is integrated into the quantiser.

The quantisation process is carried out by changing the quantisation matrix to achieve different operating points, similar to [2, 3, 6]. The bit planes of the quantised DCT coefficient bands are extracted by grouping the bits of equal significance (e.g. the most significant bit) in the quantised symbols in one band to form bit plane arrays. In the transform domain DVC architectures proposed in [2, 3], these arrays are sequentially turbo encoded by taking a full bit plane as an input block to the encoder. In contrast, the proposed algorithm employs a smaller block-based input structure for the TTCM encoder. The block length is a trade-off between the coding strength of the TTCM coder and the efficiency of the dynamic block-based parity request mechanism. The optimum block length was empirically determined. In the proposed solution, the conventional TTCM structure is modified so that the parity bits for the input bit stream is generated at the encoder but the symbol mapping function is moved to the decoder. The parity bit stream is punctured and transmitted as a binary stream to the decoder as the encoded (compressed) video stream based on the feedback.

The symbol mapping algorithm encloses a QPSK modulator to combine the systematic (side information) and parity bits. The TTCM decoding algorithm is shown in Fig. 2, where a symbol based MAP algorithm is used. Owing to the side information estimation process, the systematic bit stream inherits a different noise PDF compared to the parity bits received over the channel. The branch metric calculation in the decoding algorithm is suitably modified to compensate for the dissimilar noise probability distributions contained in the TTCM symbols. The parity bits are fed into the decoder through an ‘on-demand’ approach using a reverse channel for passing the request to the parity buffer maintained in the encoder. The side information for the Wyner-Ziv frame $X_0$ is generated by performing motion-compensated interpolation using the decoded key frames $X_{2i-1}$ and $X_{2i+1}$, as in [3].

Fig. 2 TTCM decoder

Simulations results: We used the same side information technique as in [3] for all simulations to compare the results. The block length in TTCM coding is set to 10 based on experimental optimisation. The PSNR of the decoded frames and transmitted bit rate are averaged over the sequence for the luminance component. All video sequences are in QCIF ($176 \times 144$) format at a frame rate of 15 frame/s and coded with a GOP size of 2. The results for Hall Monitor (165 frames) and Soccer (150 frames) sequences are shown in Figs. 3 and 4 respectively. The simulation results are compared with transform domain DVC codecs presented in the literature and with the H.264/AVC (profile: main) in IBIBI picture format.

Fig. 3 RD performance comparison of proposed DVC codec for Hall Monitor sequence (Key frames + Wyner-Ziv frames)

It is observed that the proposed TTCM-based codec performs significantly better irrespective of the motion level compared to all turbo-coding-based DVC implementations considered. The main reason for the performance improvement is the naturally very high coding gain

ELECTRONICS LETTERS 17th July 2008 Vol. 44 No. 15
of TTCM and its inherent property of noise immunity [8]. This is clearly visible with results at different motion levels. When the motion is large, we have better rate-distortion (RD) performance gain with the proposed technique. The proposed solution is computationally less expensive than [3] since we use a constraint length of four in the component encoders and six iterations of the MAP decoder whereas in [3] they used a constraint length of five and 18 MAP decoder iterations.

Fig. 4 RD performance comparison of proposed DVC codec for Soccer sequence (Key frames + Wyner-Ziv frames)

Effects of noise variance estimation: In DVC codecs, the noise variance of the side information need to be estimated for use in the maximum a posteriori (MAP)-based decoder. The effects of suboptimal noise estimation of side information were also analysed for the proposed solution. It was noted that this noise resembled both Gaussian and Laplacian distributions with distinct variance parameters depending on the high or low motion level in the sequence. In either case, it was observed that the TTCM-based decoder used in the proposed implementation shows a significant immunity to the variations in estimated noise variance. When the estimated variance is varied the proposed TTCM-based codec shows a consistent bpp (bits per pixel) whereas the Turbo-coding based codec shows a fluctuating bpp value as shown in Table 1. This observation is consistent over different motion levels as well as the distribution models using both Gaussian and Laplacian distributions.

Table 1: Bits per pixel for TC and TTCM based codecs for different estimations of noise variance in side information

<table>
<thead>
<tr>
<th>Estimated noise variance</th>
<th>Gaussian distribution</th>
<th></th>
<th>Laplacian distribution</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>bpp</td>
<td>Estimated noise variance</td>
<td>bpp</td>
<td></td>
</tr>
<tr>
<td>0.4</td>
<td>0.179 0.152</td>
<td>0.179 0.152</td>
<td></td>
<td></td>
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<tr>
<td>0.8</td>
<td>0.178 0.152</td>
<td>0.179 0.152</td>
<td></td>
<td></td>
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<tr>
<td>1.6</td>
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<td>0.183 0.152</td>
<td></td>
<td></td>
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<tr>
<td>2.0</td>
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<td>0.179 0.152</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.0</td>
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<td>0.179 0.152</td>
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<td></td>
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<tr>
<td>10.0</td>
<td>0.179 0.152</td>
<td>0.179 0.152</td>
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</tbody>
</table>

Conclusions: A TTCM-based transform domain DVC codec is proposed. It has been shown that the proposed codec outperforms the turbo-coding-based transform domain DVC codecs with a significant PSNR gain for all sequences considered. Furthermore, for some sequences it is evident that the proposed codec can even outperform H.264/AVC codec at low bit rates, which is a very significant step forward in DVC research.

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ELECTRONICS LETTERS 17th July 2008 Vol. 44 No. 15