

JOINT DATA COMPRESSION AND ERROR PROTECTION FOR COLLABORATIVE TRANSMISSION

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ABSTRACT

This paper addresses the problem of efficient and robust transmission of video over a hierarchical wireless infrastructure. First, we compress the data generated by the video sources using a multi-resolution wavelet coder. Subsequently, the generated bitstreams are transmitted over a wireless infrastructure to multiple regional processing centers (RPCs), which then send the distorted bitstreams to a common higher-level processing center/receiver. We propose a symmetric framework to the joint compression and error protection of the correlated video bitstreams received by the RPCs. We show that significantly improved video performance can be obtained by our framework over a variety of channel conditions.

1. INTRODUCTION

The problem of source coding and joint source-channel coding for correlated sources has recently received a lot of attention, due to its applicability to many wireless streaming scenarios. As stated by the Slepian-Wolf Theorem [1], correlated sources can be compressed up to their joint entropy even though the source coding is performed separately, as long as the joint distribution of sources is known and decoding is performed jointly. By exploiting the correlation information between different sources at the decoder side, low complexity distributed encoding can achieve the same efficiency as joint encoding. Thus, proper design allows complexity transfer from the encoder to the decoder without performance loss. Pradhan et al. [2] first applied channel coding concepts for the compression of correlated sources. Subsequently, several efficient compression schemes based on Turbo codes [3] [4] [5] [6] and LDPC codes [7] have been proposed to address similar transmission scenarios. Distributed source coding (DSC) has also been applied to image and video coding [8] [9].

Until now, most existing papers have focused on the asymmetric coding of two correlated sources which assumes that only one source is compressed and the other one (side-

information) is known perfectly at the decoder. This unbalanced compression and transmission scenario implicitly gives different priorities to different sources. Symmetric DSC is more versatile and has more benefits for generic wireless systems. Several symmetric joint source-channel coding schemes have been proposed in [10] [11], with the output rate of the encoder higher than the input rate.

In this paper, we propose a joint compression and error protection coding scheme for correlated binary sources based on LDPC codes. This scheme maintains the powerful error correcting capability of LDPC codes while still allowing compression. Also as a symmetric coding scheme, it can be directly generalized to compression and decoding of more than 2 correlated binary sources

The rest of this paper is organized as following: In Section 2, a practical scenario is described that clearly matches the problem we attack. Next, our compression scheme based on LDPC codes is described. The decoding strategy is outlined. Simulation results are shown in Section 5. Finally, Section 6 provides the concluding remarks.

2. PROBLEM DESCRIPTION

There are numerous applications involving correlated sources. We consider a (wireless) network system in which a user signal is received by more than one intermediate node, referred to as regional processing center (RPC). A typical example of such a scenario is common in an overlapping cellular coverage. The RPC gathers and processes received (video) signals from transmitters in its coverage area. An overlapped coverage allows each transmitter to reach more than one RPCs, albeit with different reliability.

In most wireless networks, lower level nodes are typically less complex and have stringent constraints on power. This prompts the concept of distributed coding and data compression at sensors and RPCs in order to achieve efficient and robust compression and transmission, while transferring the complexity to receivers at higher level nodes. In the hierarchical wireless sensor network such as mobile communication network, each regional processing center

(RPC) gathers and processes sensor data from their coverage domain and sends sensor data to the next level data fusion centers.

In this shared media, due to the overlapping of coverage domains, each RPC receives signals from a group of sensors some of which are partially covered by other RPCs. As a result, data received by neighboring RPCs are not independent. This new form of data correlation can be exploited effectively by designing new, distributed, joint compression and error protection (JCEP) codes.

For illustration, we show in Fig 1, how data transmitted by a sensor is received by two adjacent RPCs. Both RPCs receive noisy signals that represent the original source bit-stream b_k . Thus, the two detected bit-streams x^1 and x^2 are obtained as outputs of two random binary symmetric channels (BSC) that have a common input b_k . We view this as a form of collaborative binary transmission.

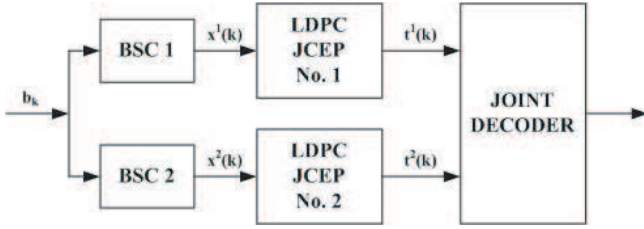


Fig. 1. Collaborative data transmission joint decoding.

It should be noted that this collaborative binary transmission model can also be employed in other practical scenarios. One example is in streaming data over different wireless paths over ad-hoc networks. Also in systems where ARQ is used, the same data stream are re-transmitted to the RPC receiver.

We now describe our new distributed encoding strategy.

3. JOINT DATA COMPRESSION AND ERROR PROTECTION

Now we present a practical symmetric compression scheme for the above correlated sources which achieves good error protection ability using high rate (n,k) LDPC code.

We divide the binary source in blocks of length K . The information sequence transmitted by the sensor is denoted as $\mathbf{b} = [b_1, b_2, \dots, b_K]$. This message sequence is received with different distortion by two RPCs. We denote the 2 RPC receptions as

$$\mathbf{x}^1 = [x_1^1, x_2^1, \dots, x_K^1] \text{ and } \mathbf{x}^2 = [x_1^2, x_2^2, \dots, x_K^2].$$

With transmission errors, the relationship between \mathbf{b} and $\mathbf{x}^1, \mathbf{x}^2$ can be modelled as 2 separate BSC channels with known crossover probability of p_1 and p_2 respectively. Our goal is to compress $\mathbf{x}^1, \mathbf{x}^2$ distributively and symmetrically.

For the conventional asymmetric source codings scheme

based on LDPC codes [7], \mathbf{x}^1 will be looked as a corrupted codeword, which is multiplied by the low density parity check matrix. Compression is achieved by only transmitting the syndrome. This syndrome coding was first introduced in [2]. In our approach, we encode both sequences \mathbf{x}^1 and \mathbf{x}^2 using LDPC codes. The two full LDPC codewords are $[s^1 \ c^1]$ and $[s^2 \ c^2]$. This encoding step is similar to the LDGM codes used in [11]. However, we do not need to limit our proposed framework to the LDGM codes, which are a subclass of LDPC codes. We can choose different codes for various rate-distortion-complexity requirements.

The parity bits of different encoders are not correlated. For data compression, each encoder punctures only half of information bits. Either random puncturing or regular puncturing can be used. As an example, we will puncture odd information bits in one encoder and even information bits in the other.

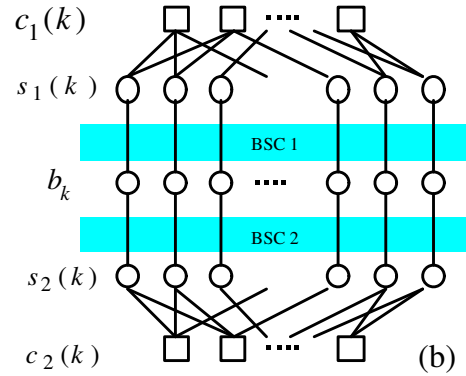


Fig. 2. Joint decoding mechanism

On the decoder side, conventional iterative belief propagation decoding algorithm for LDPC is performed based on the bipartite graph shown in Fig. 2. In order to perform this algorithm, each decoder must acquire half of the information bits from the soft information exchange between the 2 decoders. Denote the output Log Likelihood Ratio (LLR) of the information bits from LDPC decoder as

$$S(x_i^l) = \log\left(\frac{Pr\{x_i^l = 1|r^l\}}{Pr\{x_i^l = 0|r^l\}}\right), l = 1, 2; i = 1, 2, \dots, k$$

By exchanging the soft information several time. Two decoders output LLR of the decoded sequence \mathbf{x}^1 and \mathbf{x}^2 . Final joint decoder processes this soft information and produces the LLR of decoded sequence $\hat{\mathbf{b}}$ from the relationship.

$$S(\hat{b}_i) = \log\left(\frac{(1-p_1)e^{S(x_i^1)} + p_1}{p_1e^{S(x_i^1)} + (1-p_1)}\right) + \log\left(\frac{(1-p_2)e^{S(x_i^2)} + p_2}{p_2e^{S(x_i^2)} + (1-p_2)}\right)$$

4. APPLICATION TO VIDEO STREAMING

To enable robust and flexible transmission of video over wireless networks, scalable compression schemes, e.g. motion compensated wavelet video schemes, can be employed. In [12][13], we proposed a 3D multi-resolution wavelet video coding scheme referred to as In-Band Motion Compensated Temporal Filtering (IBMCTF). IBMCTF is more suitable for the encoding and adaptive transmission of video over heterogeneous networks to diverse capability devices than conventional motion-compensated wavelet video coding techniques due to the following advantages:

- improved coding efficiency;
- true multi-resolution representation of the content by enabling adaptation of temporal-resolution (frame-rate) per spatial resolution level;
- improved complexity scalability (e.g. different temporal filtering strategies can be employed for the different resolutions spatial bands).

This video coder will be tested with our JCEP codes in the simulation.

5. SIMULATION RESULTS

We test our proposed scheme in a wireless network scenario. The simulation condition is summarized as follows:

- Two BSCs have $p_1 = p_2 = 10^{-5}$
- A (1020,766) Regular LDPC Code [14] is used in both RPCs transmitters to achieve a compression ratio of 5/6. Specifically, for every block of 766 information bits into the encoder, 254 parity check bits are generated. Together with half of the information bits (383), a total of 637 bits are transmitted. input bits.
- Each LDPC decoder iterates 20 times after which soft information is exchanged up to 5 times. This joint decoding process will stop either after 5 iterations or when the decoded sequences satisfy the parity check equations.

Figure 3 shows the resulting frame error rate (FER) improvement. The FER is shown for a) single RPC transmission without compression, b) dual transmission by (both) RPCs without compression and c) JCEP encoding and joint iterative decoding. The detector for scenario b) performs a maximum likelihood combining. The results illustrate that the JCEP strategy not only increases the throughput performance, but also significantly reduces the FER.

To illustrate the impact of the proposed JCEP system on video performance, we show in Table 1 the PSNR for

various sequences encoded at 300kbps using the IBMCTF coder. Sequences exhibiting PSNR values lower than 15dB result in a very poor visual quality. The results illustrate the advantages of using JCEP as opposed to (a) single RPC and (b) 2 RPC transmission without compression. Note that, for these results, no unequal error protection (UEP) was deployed for the various multi-resolution layers. If UEP were employed (though e.g. MAC layer ARQ or application layer FEC), improved results would have been obtained for the 2 RPC case given an E_b/N_0 above 5dB.

In the above FER case, two sources \mathbf{x}^1 and \mathbf{x}^2 are highly correlated since the error probability is 10^{-5} . In order to better understand the performance of the proposed JCEP scheme, we also test the case when the BER is much higher at $p_1 = p_2 = 10^{-3}$. In this case due to high loss in two BSCs, full frame recovery may require additional coding. Here the bit error rate (BER) is shown in Fig 4. Similar to Fig 3, a improvement of about 5-6 dB is also achieved compared with dual transmission without compression.

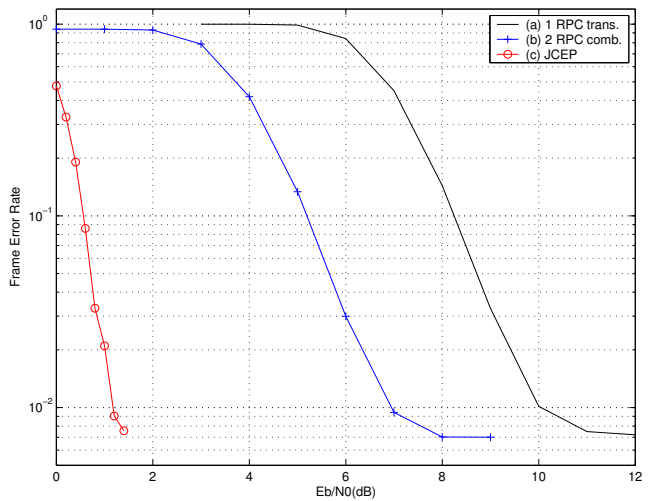


Fig. 3. Frame Error Rate Performance of our proposed JCEP scheme with $p_1 = p_2 = 10^{-5}$

6. CONCLUSION

We propose a symmetric approach to the joint compression and error protection of correlated video bitstreams. We show that standard LDPC codes can be adopted for rate reduction and error protection. In addition to providing compression, this coding scheme also has strong error correction capability. Simulation results demonstrate the effectiveness of this method for video and packetized data transmission.

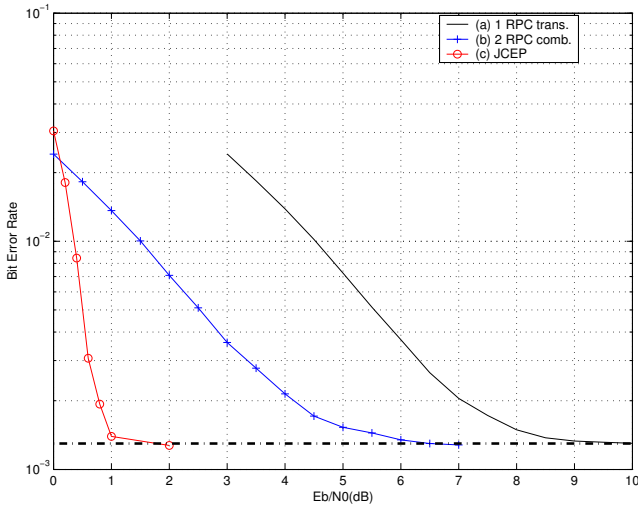


Fig. 4. Bit Error Rate Performance of our proposed JCEP scheme with $p_1 = p_2 = 10^{-3}$

Table 1. PSNR performance improvement (in dB) for different E_b/N_0 using JCEP strategies

Sequences (coded @ 300kbps)	PSNR $E_b/N_0 = 4dB$			PSNR $E_b/N_0 = 5dB$			PSNR $E_b/N_0 = 7dB$		
	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)
foreman	< 10	< 10	29.4	< 10	23.4	29.4	< 10	27.12	29.43
Coastguard	< 10	< 10	26.5	< 10	23.0	26.5	< 10	25.03	26.50

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