MULTI-CHANNEL ADAPTIVE BIT ALLOCATION AND ERROR CONTROL FOR VIDEO TRANSMISSION OVER WIRELESS NETWORKS

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ABSTRACT

Multiple Description Coding (MDC) has proven to be a powerful tool for joint source/channel coding applications. Indeed, MDC offers the possibility of controlling easily the amount of redundancy introduced in the transmitted signal while maintaining good quality decoding even when the channel is noiseless. However, to our knowledge, few work have been dedicated to the tuning of the redundancy parameter according to the channel noise level. Moreover, in case of non stationary channel a solution must be found to adapt automatically the amount of redundancy in order to maintain transmission quality.

In this paper, we propose a MDC method that estimates the amount of source redundancy that must be dispatched between the different descriptors according to the channel state. This method includes a wavelet transform and an optimal bit allocation process of the binary ressources across the different descriptors and the different wavelet subbands. It takes into account the knowledge of the channel impulse response which is time variable and reflects accurately the propagation conditions encountered in a real environment. We focus on radio frequency wireless transmission. The proposed method is well suited for wideband mobile communications where the channel can be modeled as a superposition of a discrete number of paths. Simulations of the proposed MDC for different number of descriptions and redundancies are performed giving very encouraging results compared with other state-of-the-art MDC.

1. INTRODUCTION

Recent advances in wireless communications have made possible the transmission of multimedia content over wireless channels. The Wireless channels are known to be error prone what seriously deteriorates the quality of the transmitted signals. In such conditions robust compression schemes are very important especially for transmission at low bit rates. Therefore, it is important to devise encoding/decoding schemes that can make the compressed bitstream resilient to transmission errors. It is also necessary to design proper interfacing mechanisms between the codec and the network, so that the codec can adjust its operations based on the network conditions.

To make the compressed bitstream resilient to transmission errors one must add redundancy to the stream, so that it is possible to detect and correct errors. Typically, this is done at the channel by using Forward Error Correction codes (FEC). However, it is known the difficulty of FEC in dealing with variable channels presenting bursts.

An other solution is to use Multiple Description Coders (MDC). A MDC dispatch the redundancy between different descriptions of the same source and permits quality scalability since each description correctly received improves the decoder performance. Also, MDC does not require prioritized transmission, as each description is independently decodable. Some MD methods exploits the natural correlation between symbols for reconstruction. These explicit redundancy techniques have the additional advantage of providing very simple mechanisms for adaptation to changing network conditions. The key observation is that the level of redundancy can be selected by determining the number of times a given sample is transmitted, and how many bits should be used for each of the redundant representations.

The proposed method is based on the Multiple Description Bit Allocation algorithm presented in [1]. This wavelet-based method exploits the channel capacity to compute the amount of explicit redundancy to be dispatched between two different transmission channels (or equivalently two descriptors). The channel capacity reflects long term behavior of the channel. This measure is thus not sufficient when channels are highly non-stationary as for wireless communication systems. Moreover, for wideband mobile communications, where the channel can be modeled as the superposition of a discrete number of paths [2] it is necessary to generalize the proposed MDC to M channels (with $M > 2$).

In this paper we propose a generalization of the method proposed in [1] to M channels with different noise characteristics. The paper is organized as follows. In section 2 we presents the global scheme of Multi-channel coding. The proposed MD allocation for M channels is developed in section 3. Then, in section 4 we propose a solution to estimate the amount of redundancy to dispatch accross the different descriptors based on the estimation of the impulse response of the channel. Finally, section 5 presents some first simulation results and section 6 concludes the paper.

2. MULTI-CHANNEL ADAPTIVE ALLOCATION

In the proposed method, explicit redundancy is introduced so that each sample of the input signal is transmitted more than once and coded with different accuracy levels. More precisely, a Discrete Wavelet Transform (DWT) is first performed on input signal and then, the resulting wavelet coefficients are repeated in the several descriptions of the MD coder. The main idea is that, when a group of coefficients is finely coded in one description it will be coarsely coded in the others.

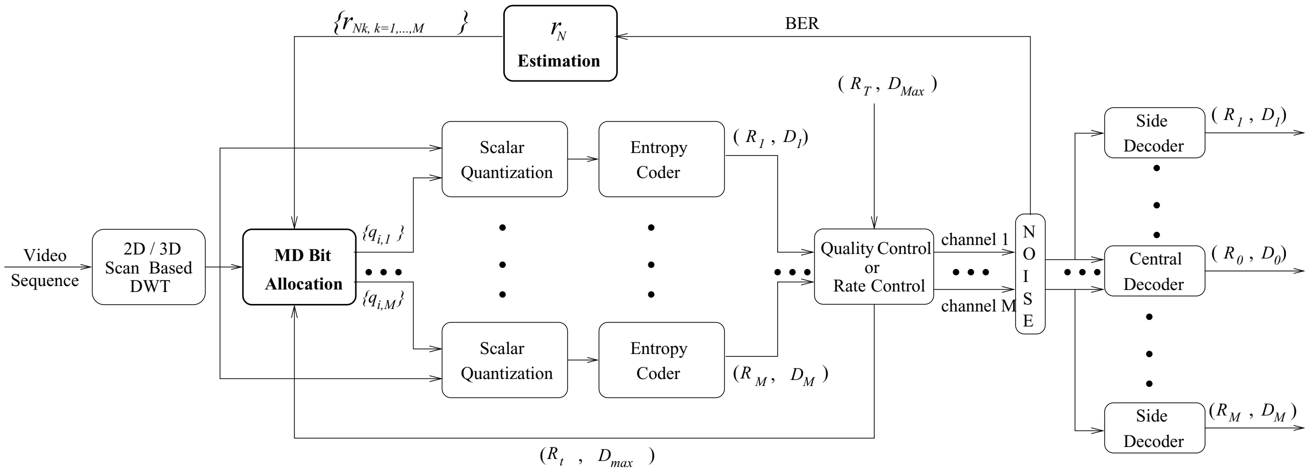

Figure 1: Complete Coding Scheme

The proposed coding scheme is presented in figure 1. We can divide our problem in two main steps:

MD Bit Allocation The goal of this step is to find, *for a given redundancy between the descriptions*, the combination of scalar quantizers across the various wavelet coefficient subbands that will produce the minimum total central distortion while satisfying the side bit rate constraints. For this purpose we generalize the method presented in [1] to M channels. This generalization is described in (section 3). It is important since it permits to construct a multi-channel adaptive allocation codec. This proposed codec is well suited for wideband mobile communications where the channel can be modeled as the superposition of a discrete number of paths [2].

r_N **Estimation** We pretend to take into account the time varying error behavior of fading radio channels. We remember that an r_N estimation was proposed in [1] that uses channel capacity. Such estimation may not be adequate to capture short term changes in the channel. An r_N estimation adapted to radio frequency is thus presented in 4.

3. PROPOSED MD BIT ALLOCATION

For a system considering N subbands of a wavelet decomposition, we minimize the central distortion D_0 for a total bit rate R_T. Then, the purpose of the bit allocation for a MD scheme is to determine the optimal sets of quantization steps $\{q_{i,j}\}, i = 1,...,N$ for descriptions $j = 1,...,M$. The parameter R_T is given for the bit allocation (Fig. 1).

Th proposed bit allocation problem can be expressed as:

$$(P)\begin{cases} \textbf{min}\ D_0(\{q_{i,1},...,q_{i,M}\}) \\ \textbf{Constraints}\ f(R_j) \leqslant 0 \end{cases} \quad (1)$$

Where $R_j, j = 1,...,M$, is defined in equation (2) and $f(x) = x - \frac{R_T}{M}$ for all $x \in \mathbb{R}$.

$$R_j = \overset{N}{\underset{i=1}{\quad}} a_i R_{i,j}(q_{i,j}), \text{ for all } j \in \{1,...,M\}. \quad (2)$$

The parameter a_i in equation (2) is the size of the subband (i) divided by the size of the input source and $R_{i,j}(q_{i,j})$, is the output bit rate in bits per sample for the ith subband.

These bit allocation problem is a constrained problem which can be solved by introducing the Lagrange operators. The Lagrangian functional for the constrained optimization problem is given by equation (3), where $\ _j$ is the Lagrangian parameter.

$$J(\{q_{i,1},...,q_{i,M}\}) = D_0 + \overset{M}{\underset{j=1}{\quad}} \ _j f(R_j). \quad (3)$$

For a source with generalized Gaussian distribution [3], the central distortion, D_0 in equation (3) can be written as presented in equation (4).

$$D_0 = \overset{N}{\underset{i=1}{\quad}} \ _i w_i \ {}^2_{i,0} D_{i,0}(\{q_{i,1},...,q_{i,M}\}). \quad (4)$$

The $\ {}^2_{i,0} D_{i,0}(\{q_{i,j}\})$ is the central Mean Square Error (MSE) for the ith subband in the case of a Generalized Gaussian distribution, w_i are the weights used to take into account the nonorthogonality of filter bank [4] and $\ _i$ is a perceptual weighting. For the calcul of the central distortion of a subband i, $D_{i,0}(\{q_{i,j}\})$ we propose equation (5) where r_{N_j} is the redundancy parameter associated to the redundant subbands.

$$\begin{aligned} D_{i,0}(\{q_{i,1},...,q_{i,M}\}) &= \frac{1}{\ {}^2_{i,0}} \overset{M}{\underset{\substack{j=1 \\ j\neq L}}{\quad}} r_{N_j} \ {}^2_{i,j} D_{i,j}(q_{i,j}) + \\ & \quad \frac{1}{\ {}^2_{i,0}} \ {}^2_{i,L} D_{i,L}(q_{i,L}) \end{aligned} \quad (5)$$

where L is the description where subband i is finely coded, while its coarsely coded (with a factor r_{N_j}) in the other descriptions. Note that the redundancy parameter domain is $[0,1]$. The $r_N = 0$ is used when the channel is noiseless and the $r_N = 1$ is used when a very noisy channel is expected.

The Lagrangian functional (3) can be rewritten as in equation (6).

$$
\begin{aligned}
J(\{q_{i,1},\dots,q_{i,M}\}) &= \mathop{}_{i=1}^{N} \;{}_iw_i\; {}^{2}_{i,0}D_{i,0}(\{q_{i,1},\dots,q_{i,M}\}) \\
&+ \mathop{}_{j=1}^{M} \;{}_j\left(\mathop{}_{i=1}^{N} a_iR_{i,j}(q_{i,j}) - R_T/M\right)
\end{aligned}
\tag{6}
$$

The solution of (6) is obtained when

$$
\begin{cases}
\dfrac{J(\{q_{i,1},\dots,q_{i,M}\})}{q_{i,j}} = 0, & \text{for all } j = 1,\dots,M \\[2ex]
\dfrac{J(\;q_{i,1},\dots,q_{i,M}\})}{{}_j} = 0 & \text{for all } j = 1,\dots,M.
\end{cases}
\tag{7}
$$

The derivative in ${}_j$ is presented in equation (8).

$$
\frac{J(\;q_{i,1},\dots,q_{i,M}\})}{{}_j} = \mathop{}_{i=1}^{N} a_iR_{i,j}(q_{i,j}) - R_T/M \tag{8}
$$

The derivative in $q_{i,j}$ is

$$
\begin{aligned}
\frac{J(\{q_{i,1},\dots,q_{i,M}\})}{q_{i,j}} &= {}_iw_i\; {}^{2}_{i,0}\frac{D_{i,0}(\{q_{i,1},\dots,q_{i,M}\})}{q_{i,j}} + \\
&\quad {}_ja_i\frac{R_{i,j}(q_{i,j})}{q_{i,j}}
\end{aligned}
\tag{9}
$$

where $\dfrac{D_{i,0}(\{q_{i,1},\dots,q_{i,M}\})}{q_{i,j}}$ can be calculated from equation (5) as

$$
\begin{aligned}
\frac{D_{i,0}(\{q_{i,1},\dots,q_{i,M}\})}{q_{i,j}} &= \frac{1}{{}^{2}_{i,0}} \mathop{}_{\substack{j=1 \\ j\neq L}}^{M} r_{N_j}\; {}^{2}_{i,j}\frac{D_{i,j}(q_{i,j})}{q_{i,j}} + \\
&\quad \frac{1}{{}^{2}_{i,0}}\; {}^{2}_{i,L}\frac{D_{i,L}(q_{i,L})}{q_{i,j}}
\end{aligned}
\tag{10}
$$

We can simplify equation (10) as presented in equation (11) where $C_{i,j}$ is defined in equation (12).

$$
\frac{D_{i,0}(\{q_{i,1},\dots,q_{i,M}\})}{q_{i,j}} = \frac{1}{{}^{2}_{i,0}}C_{i,j}\; {}^{2}_{i,j}\frac{D_{i,j}(q_{i,j})}{q_{i,j}} \tag{11}
$$

$$
C_{i,j} = \begin{cases} 1, & \text{if } j = L \\ r_{N_j}, & \text{otherwise.} \end{cases} \tag{12}
$$

Using equation (11) we can rewrite derivative in $q_{i,j}$ (equation (9)) as

$$
\begin{aligned}
\frac{J(\{q_{i,1},\dots,q_{i,M}\})}{q_{i,j}} &= {}_iw_iC_{i,j}\; {}^{2}_{i,j}\frac{D_{i,j}(q_{i,j})}{q_{i,j}} + \\
&\quad {}_ja_i\frac{R_{i,j}(q_{i,j})}{q_{i,j}}
\end{aligned}
\tag{13}
$$

Thus, we have

$$
\begin{aligned}
&{}_iw_iC_{i,j}\; {}^{2}_{i,j}\frac{D_{i,j}(q_{i,j})}{q_{i,j}} + {}_ja_i\frac{R_{i,j}(q_{i,j})}{q_{i,j}} = 0 \Leftrightarrow \\
&\frac{D_{i,j}(q_{i,j})}{R_{i,j}(q_{i,j})} = \frac{-\;{}_ja_i}{{}_iw_iC_{i,j}\; {}^{2}_{i,j}}
\end{aligned}
\tag{14}
$$

Finally,using equations (8) and (14) the system (7) can be rewrite as system (15).

It can be showed that the solution of this allocation problem is given by solving the system (15) which has $M\times(N+1)$ equations and $M\times(N+1)$ unknowns. The solution provides the optimal sets of quantization steps $\{q_{i,1}\}$,..., $\{q_{i,M}\}$, for a given sequence of redundancy parameters $r_{N_j}, j = 1,\dots,M$.

$$
\begin{cases}
\dfrac{D_{i,1}}{R_{i,1}}(q_{i,1}) = \dfrac{-\;{}_1a_i}{{}_iw_i\; {}^{2}_{i,1}C_{i,1}} \\[2ex]
\dots \\[2ex]
\dfrac{D_{i,M}}{R_{i,M}}(q_{i,M}) = \dfrac{-\;{}_Ma_i}{{}_iw_i\; {}^{2}_{i,M}C_{i,M}} \\[2ex]
{}^{N}_{i=1}\, a_iR_{i,1}(q_{i,1}) - R_T/M = 0 \\[2ex]
\dots \\[2ex]
{}^{N}_{i=1}\, a_iR_{i,M}(q_{i,M}) - R_T/M = 0
\end{cases}
\tag{15}
$$

The ${}^{2}_{i,j}D_{i,j}(q_{i,j})$, $j = 1,\dots,M$ are the MSE for the ith subband in the case of a Generalized Gaussian distribution.

Note that by using bit allocation to determine the level of redundancy, not only the encoder can adjust itself in a simple manner, but in addition the decoder can handle packets with different levels of redundancy without requiring any significant changes to its structure.

The main problem of this bit allocation is to choose intermediate redundancies, and implicitly intermediate values of r_{N_j} parameter. Remember that we want the amount of redundancy, i.e., the importance of the redundant subbands, to depend on the channel characteristics. For this purpose, in the next section we propose a method to compute the r_N parameter using channel impulse response.

4. R_N ESTIMATION FOR ERROR CONTROL

The r_N estimation is proposed here to take into account the time varying behavior of the fading radio channels.

The presented method uses the channel impulse response (CIR) to adapts to radio frequency wireless transmissions. The CIR is time variable and accurately reflects the propagation conditions encountered in real environment.

We propose to compute the matrix channels $H_k(t), k = 0,\dots,W$ for the W radio channels, as detailed in [5] for CDMA systems or in [6] for OFDM systems. These matrices are computed from

$$
H = (h_1^T, h_2^T, \dots, h_W^T), \tag{16}
$$

where

$$
h_w = (h_{1,w}, h_{2,w}, \dots, h_{K,w}),\; w = 1,\dots,W \tag{17}
$$

are the channel impulse response of finite order K. Note that the vector channels h_w, $w = 1,...,W$ have different and time variant transmission qualities, resulting from the characteristics of the frequency selective wireless fading channel. We conclude that this channel information should be used when developing joint source channel coders for wireless transmissions. We present in the following how we use this information for the redundancy estimation of our multiple description coder.

A good measure of a matrix energy is given by the Frobenius norm of the matrix

$$H_k^+(t) = \left(H_k^H(t)H_k(t)\right)^{-1} H_k^H(t), \tag{18}$$

where $[]^H$ denotes complex conjugate transpose. So, the smaller the Frobenius norm is, the better transmission quality the corresponding channel is expected to provide [6].

We propose to use this norm to estimate the values $r_{N_k}, k = 1,...,W$ as presented in equation (19)

$$r_{N_k} = ||H_k^+||_F = \sqrt{trace(H_k^+ (H_k^+)^H)}. \tag{19}$$

At the receiver, a channel behavior estimation is obtained adaptively from a periodic training or pilot signal. This information is sent back to the transmitter, so the transmitter can use this information to compute the redundancy parameter to optimally allocate the available vector channels.

5. SIMULATIONS

For 1 bpp central bit rate and 512×512 *Lena* image, central PSNR vs. side PSNR is plotted in Fig. 2 and Fig. 3 for various values of r_N between 0 and 1.

We compare our application with the best Multiple Description Coding techniques we know to date that are presented in [7, 8].

Results for different number of descriptions will be presented in the final version.

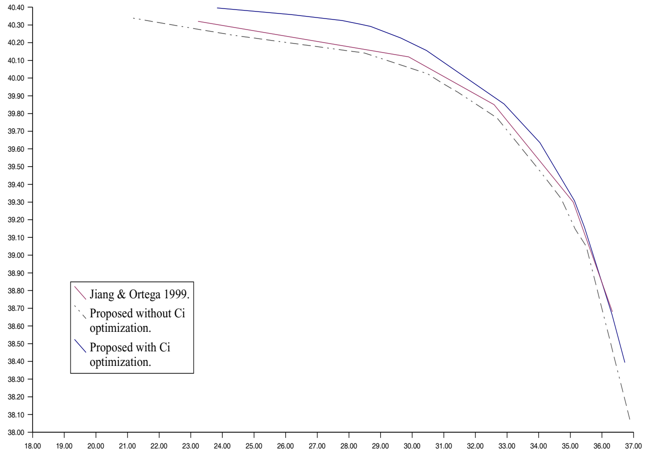

Figure 2: Side PSNR vs Central PSNR. Comparison of the proposed method with the method in[8]

6. CONCLUSIONS

We present an MDC method for M channels where the redundancy estimation applied to each description is estimated on the channel information. The descriptions redundancy is thus estimated using the channel impulse response, characterized by Frobenius norm metrics based on channel estimation at receiver. This information is sent back periodically to the transmitter.

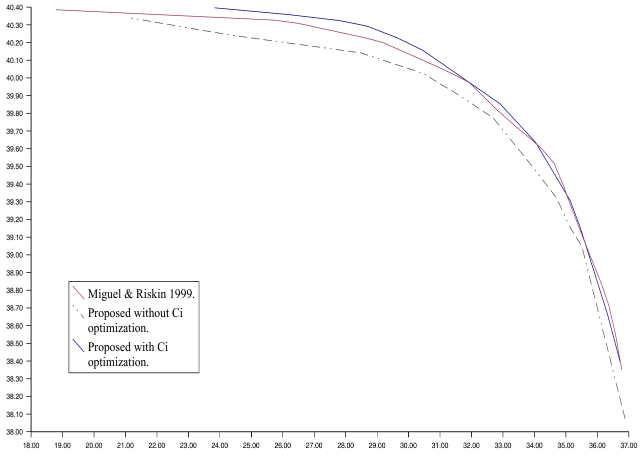

Figure 3: Side PSNR vs Central PSNR. Comparison of the proposed method with the method in[7]

REFERENCES

[1] M. Pereira, M. Antonini, and M. Barlaud, "Multiple description image and video coding for wireless channels," *EURASIP Signal Processing: Image Communication, Special issue on Recent Advances in Wireless Video*, 2004.

[2] D.J. Grenwood and L. Hanzo, "Characterization of mobile radio channels," in *Mobile Radio Communications*, R. Steele, Ed., Piscataway, NJ, 1992.

[3] M. Antonini, M. Barlaud, P. Mathieu, and I. Daubechies, "Image coding using wavelet transform," *IEEE Transaction on Image Processing*, vol. 4, no. 8, pp. 1053–1060, August 1992.

[4] B.Usevitch, "Optimal bit allocation for biorthogonal wavelet coding," in *IEEE Data Compression Conference*, Snowbird, UT, April 1996, pp. 387–395.

[5] J. Francis, *Etude des systmes de traitement numrique de canal pour la reception radio-mobile UMTS/TDD*, Ph.D. thesis, Institut National Polytechnique de Grenoble, France, September 2002.

[6] H. Zhang, X. Xia, Q. Zhang, and W.Z, "Precoded ofdm with adaptive vector channel allocation for scalable video transmission over frequency-selective fading channels," *IEEE Transaction on Mobile Computing*, vol. 1, no. 2, pp. 132–142, April-June 2002.

[7] A. Miguel, A. Mohr, and E. Riskin, "SPIHT for generalized multiple description coding," in *IEEE International Conference Image Processing*, 1999, vol. 3, pp. 842–846.

[8] W. Jiang and A. Ortega, "Multiple description coding via polyphase transform and selective quantization," in *SPIE Visual Communication Image Processing Conference*, 1999.