Implementation of an Unequal Error Protection Scheme for Scalable Foveated Image Communication

Muhammad Farooq Sabir and Rashmi Tripathi

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Abstract

Scalable Image Communication is useful in multiuser heterogenous environments. In this project, we plan to implement an unequal error protection method for Embedded Foveation Image Coding (EFIC) compressed images, using rate compatible punctured turbo codes. Different portions of the bitstream are protected unequally, based on the importance of data to the end receiver, i.e, human eye. Our prime objective is to implement this unequal error protection scheme as an embedded system for image communication over Additive White Gaussian Noise (AWGN), Rician and Rayleigh fading channels. We propose to implement and optimize this system over the TMS320C6701 DSP processor.

1 Introduction

In heterogenous environments, different users have different bandwidths and hence different data rate requirements. Scalable Image Communication is useful in such multiuser heterogenous environments. The main idea behind the scalable image communication is to send differently compressed version of the same image to different users. Images sent to the high bandwidth users are compressed using a lower compression ratio, while the images sent to the low bandwidth users are compressed using a high compression ratio. The compression ratios can also be changed with time, depending on the network conditions and the channel noise. For example, during an image communication session, if a receiver is being sent a higher data rate image (lower compression ratio), and suddenly there is network congestion, then the transmitter can change the compression ratio and send the subsequent images using a higher compression ratio. Compression ratios can also be varied when the channel SNR changes, for example, in time varying Rician and Rayleigh fading channels.

Just like the variable source coding schemes, channel coding rates can also be varied. Differently compressed versions can be protected differently using different rate channel codes and within a single image too, variable rate channel coding can be used to provide greater protection to the more important bits and lesser protection to the relatively less important ones. In the field of channel coding, this is commonly known as unequal error protection (UEP). The criterion for deciding the importance of the bits depends on the source coding technique. For example, in the embedded foveation image coding [1] (EFIC) compression method, the wavelet coefficients are weighted and ordered based on their distance from the point of fixation. The coefficients that correspond to the region near the point of fixation are encoded and transmitted first, where as the coefficients that correspond to the region farthest from the point of fixation are encoded and transmitted in the end. Hence, in EFIC, the importance criterion is based on the concept of foveation since the coefficients that correspond to the region near the point of fixation are more important than the coefficients that correspond to the regions that are away from the point of fixation. Similarly in set partitioning in hierarchical trees (SPIHT) [2] algorithm, the bitstream is ordered such that the coefficients with greater contribution to the mean-squared error (MSE) between the compressed and the original images are encoded and transmitted first.

Using this concept of the "importance" of bits, different portions of the source coded bitstreams can be protected using different rate channel codes. The motivation to have such a scheme of unequal error protection arises from the need to provide non-uniform error protection to the bits in the order of their importance. In this way, the overall number of redundant bits can be kept as low as possible, while maintaining a reasonably high quality image.

In this project, we plan to implement an unequal error protection scheme for EFIC compressed images using rate compatible punctured turbo codes [3–5], first in C and then on Texas Instrument's TMS320C6701 DSP Processor. We then plan to optimize the assembly code with respect to the computation time and memory usage. The different blocks of the proposed system, shown in Fig. 4, will be modelled as synchronous dataflow graph actors.

2 Background

A reasonably large amount of work has been done in the field of joint source-channel coding. In an unequal error protection scheme for SPIHT encoded image bitstreams, Alatan *et. al.* [6] suggested partitioning of images into three different classes. These three different classes of bit streams are then protected using the concatenated rate compatible punctured convolutional (RCPC) codes and cyclic redundancy codes(CRC). In another scheme based on a Discrete Wavelet Transform source coder, Vinay Chande and Nariman Farvardin [7] divided the bitstream into equal length packets and some sensitive bits. These two types of bits are then protected separately using banks of concatenated CRC and RCPC codes.

Another interesting unequal error protection scheme is described in [8] by Yap and Ngan. In this method, the SPIHT coded bitstream is grouped into four different significance levels. The bits from these levels are then protected using RCPC codes along with interleaving. The most significant group is protected the most, the second and third group are protected lesser as compared to the first group while the fourth group is the least protected one.

In [9] Cai *et.al.* have described the use of the RCPC codes for channel coding along with variable coefficient fixed length (VCFL) codes for source coding. A scheme used to unequally protect JPEG images using turbo codes is presented in [10] by Xiang *et.al.*. In this scheme the JPEG image is partitioned into two groups, the AC and the DC components, according to their respective sensitivity to the channel noise. Since the DC components are more sensitive than the AC components, the former are protected using a lower rate code, while the latter are protected using a higher rate code. A foveation based unequal error protection technique is presented in [11] by Lee *et.al.*. In this method the image is divided into two layers, namely, the foveated layer and the background layer. Both these layers are protected using different rate RCPC codes in order to obtain unequal error protection. Some other interesting joint-source channel coding techniques for images are discussed in [12–14]. In addition, a turbo decoder implementation using the iterative maximum a posteriori probability (MAP) algorithm on TMS320C6x is discussed in [15].

All the methods mentioned above except [11] do not take into account the human visual system (HVS) model. Better perceptual quality along with higher compression ratio and higher transmission efficiency can be achieved if the HVS is taken into account for source as well as channel coding. Embedded Foveation Image Coding (EFIC) [1] is a method which compresses the images based on the importance of different wavelet coefficients for human perception. Since in EFIC, the coefficients are ordered and grouped based on the concept of foveation, therefore different levels of error protection can be applied to different groups of coefficients, protecting the most important ones the most and the least important ones the least.

2.1 Embedded Foveation Image Coding

In the embedded foveation image coding, the bits are ordered such that those bits that contribute greater to the foveated visual quality are encoded and transmitted first. A foveated image quality metric called foveated wavelet image quality index (FWQI) [1] plays an important role in the EFIC algorithm. FWQI is used to derive a visual importance weighting model which is then used to order the bitstream.

In EFIC, the wavelet transform is first applied to the original image. It is assumed that the foveation points and regions are known aprior, which are used to compute an error sensitivity-based importance weighting mask. This weighting mask is used to weight the wavelet coefficients derived from the wavelet transform. These weighted coefficients are then encoded using a modified SPIHT encoder and then transmitted to the receiver. The coordinate(s) of the fixation point(s) are also transmitted, so that the weighting mask can be regenerated at the receiver. However the overhead due to transmission of these fixation points is so small that it can be ignored for the transmission efficiency computations.

This encoded bitstream can be truncated at any point to give the different compression ratios as shown in Fig. 1.

2.2 Rate Compatible Punctured Turbo Codes

A turbo encoder consists of two *recursive systematic convolutional* (RSC) component encoders connected in parallel, separated by a random interleaver. The output of a turbo encoder consists of the systematic bits (input bits) and the parity bits generated by the

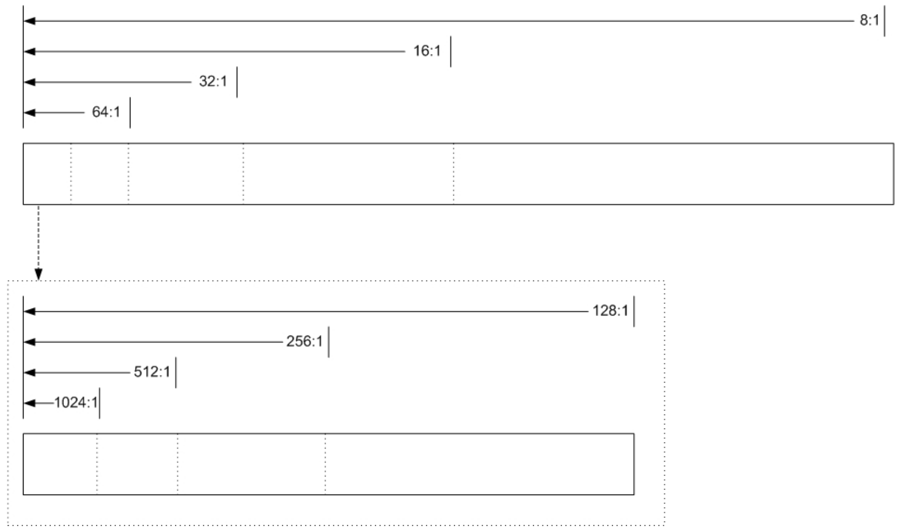

Figure 1: Different compression ratios corresponding to the different truncation points in EFIC bitstream.

two component convolutional encoders. This structure provides the turbo encoder with very powerful error correction capabilities. This happens because the interleaving reduces the probability of noise corrupting both of the parity bits corresponding to a single information bit. In addition, the output of the first decoder can be used as an apriori estimate for the second decoder and vice versa, during an iterative decoding procedure. Due to these properties and with the use of an iterative algorithm for decoding, the probability of decoding a bit incorrectly is reduced significantly. The encoder maps the k information bits into n bits to be transmitted over the channel. So the rate of the code is k/n. A few code word bits are then removed to achieve a higher rate code in order to increase the transmission efficiency. This process is known as puncturing. A family of punctured codes are rate compatible if the code-word bits from the higher-rate codes are embedded in the lower rate codes. Different rate compatible punctured turbo codes are derived from a mother convolutional code by puncturing. These different rate codes can then be used to provide unequal error protection to the different portions of the bitstream. At the receiver side, either the MAP algorithm or the Soft Output Viterbi Algorithm (SOVA), with the same trellis as that of the mother code (from which the punctured codes are derived), can be used for decoding the corrupted bitstream.

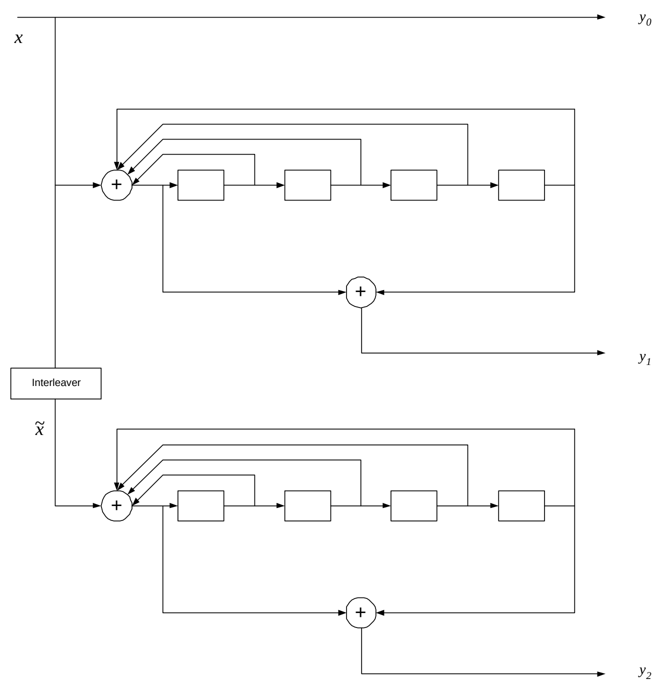

Figure 2: A Rate 1/3 Turbo Encoder

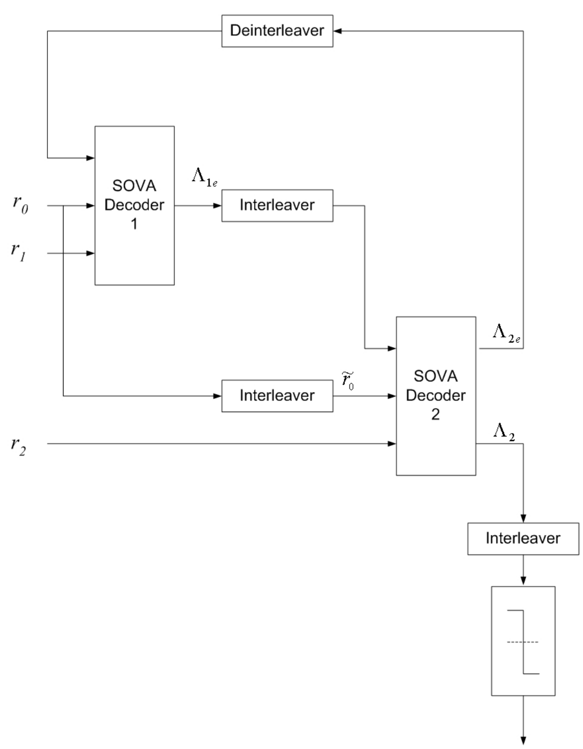

Figure 3: Iterative SOVA based Turbo Decoder [4]

3 Implementation

Since according to the EFIC compression algorithm, the most important bits for the HVS (with respect to the point of fixation) are arranged at the beginning of the bitstream, therefore, it is a natural idea to protect these bits more than the remaining portion of the bitstream. An even better idea is to provide a gradual decrease in the error protection as we move away from the start of the bitstream, since the importance of the wavelet coefficients decreases gradually as the bitstream is traversed. We plan to use rate compatible punctured turbo codes in order to provide unequal error protection to the EFIC bitstream. The block diagram for our system is shown in Fig. 4.

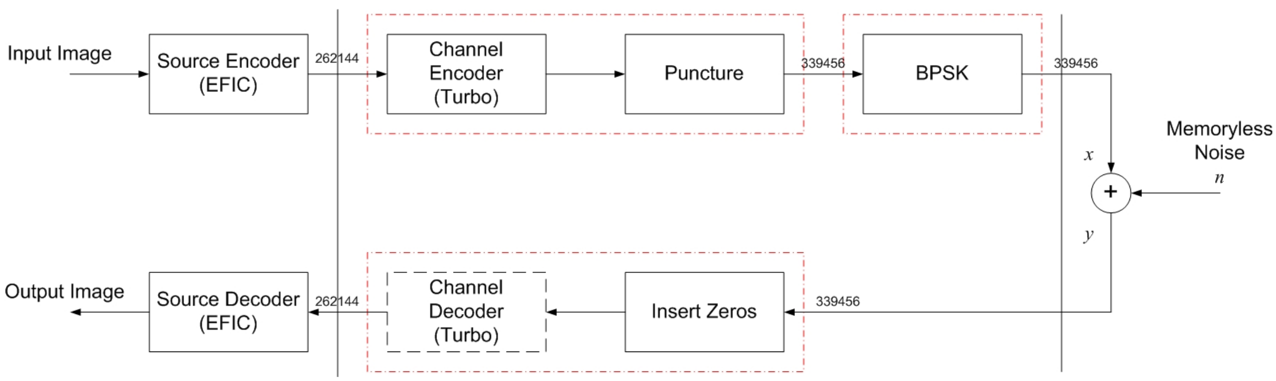

Figure 4: EFIC based image communication system with unequal error protection using Turbo Codes.

Our implementation consists of two main modules: the encoder and the decoder. The encoder consists of the turbo encoder, the puncturing block and the binary phase shift keying (BPSK) modulator, where as the decoder consists of the 'insert zeros' block and the turbo decoder. The output of the encoder will be saved as binary files and the channel noise (only to be simulated in C) will be added to these files. These corrupted files will then be passed as an input to the decoder.

The decoding of the turbo codes can be performed using the MAP algorithm or the Maximum Likelihood (ML) algorithm based on the overall trellis of the code. However, both these methods can be implemented only for small interleavers and are too complex for medium and large interleavers. One of the major practical importance of turbo codes is the use of simple suboptimum algorithm for decoding. One important point why simple MAP decoding is not practical is that the overall trellis for the turbo codes is time varying and the number of states grow exponentially with the size of the interleaver in the turbo codes. Hence the MAP algorithm can only be used to decode in the case of very short interleavers. Due to these reasons, iterative decoding algorithms are used to decode the turbo codes. Different iterative decoding algorithms like the iterative MAP, the iterative Log-Map and the iterative SOVA are used to decode the turbo codes. In this project, we will only use iterative SOVA because it is shown in [4, 16] that the complexity of the iterative SOVA is much lower than that of the iterative MAP and the iterative Log-MAP algorithms. The demodulator block is not required because the input to the SOVA needs to be the signal without demodulation in order to allow soft decisions to be made.

Since in this case, the number of inputs and outputs are fixed (fixed sized images), therefore the entire system including SOVA can be statically scheduled. Hence, each group of blocks enclosed within the dotted lines in Fig. 4 can be modelled as an SDF actor. However, the generic SOVA decoder can be modelled as a boolean dataflow graph (BDF) actor to make it compatible with the multirate DSP applications.

An open issue is to provide UEP, using rate compatible punctured turbo codes for encoding and SOVA for decoding, for the EFIC compressed images as an embedded system. In this project, we intend to address this issue by implementing this system over the TMS320C6701 DSP processor. All the modules shown in Fig. 4 will be implemented in C and will be converted into the above mentioned DSP processor assembly. The assembly code will be optimized with respect to computation time and memory usage. This embedded system will be tested over the AWGN, Rician and Rayleigh fading channels.

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