Generalized Multiple Description Coding through Unequal Loss Protection

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Abstract

In this paper we present an approach to the generalized Multiple Description problem that is fundamentally different from previously published algorithms. Our approach uses explicit channel coding in the form of Unequal Loss Protection to obtain a solution that incorporates many important properties: it can be used with any progressive source coder; it generates a balanced encoding with information equally dispersed among the descriptions; it adds a quantifiable amount of redundancy; it adapts that amount of redundancy to expected channel conditions; and it can optimize for different distortion measures. These properties allow the system to gradually improve image quality as the number of received descriptions increases. We compare our system to previously published results and show that forward error correction in Multiple Description coding can surpass them by a significant margin.

1. Introduction

In generalized Multiple Description (MD) coding [1], N descriptions of a source are transmitted to a receiver, but potentially less than N are received. This situation commonly occurs in transmissions over the Internet, where network congestion causes packet loss. The goal is to maximize the quality of the reconstruction given a set of received packets and the descriptions they contain. Other MD–related papers include [2, 3, 4, 5, 6, 7]. However, many of these works do not consider the potential of forward error correction (FEC). A notable exception is the work of Puri, Ramchandran, and Kozintsev [8].

We use systematic Reed-Solomon (RS) codes to generate FEC. These codes are very effective at recovering erased symbols when the locations of the erased symbols are known. In the MD framework, a description will arrive perfectly intact or not be received at all, so we can consider RS codes that are optimized only for recovering erased symbols [9] and ignore their error-correcting capabilities. These maximum distance separable block codes are denoted by a pair (N, k), where N is the block length and k is the number of source symbols. When the code is systematic, the first k of the N encoded symbols are the source symbols, and the remaining $N-k$ symbols are redundancy. They have the property that an (N, k) code can exactly recover the k source symbols from any size k subset of the N total symbols. This recovery is possible by treating the source symbols as the coefficients of a polynomial in a Galois field and evaluating it at a number of additional points, thus creating redundant data.

2. Unequal Loss Protection

Unequal Loss Protection [10, 11] (ULP) is a system that combines a progressive source coder with a cascade of RS codes to generate an encoding that is progressive in the number of descriptions received, regardless of their identity or order of arrival. ULP was inspired by the work on Priority Encoding Transmission [12] that protects video data against packet loss. Here, we present a brief overview of the use of ULP for MD coding (MD-ULP).

Assuming that each of the N descriptions is of equal length, we form a coding block B_i by taking the ith byte from each of the descriptions, for a total number of coding blocks equal to the length of each description. As an example, in Figure 1, coding block B_2 is circled. Each block is an independent (N, k) RS code, with N fixed to be the number of descriptions. For each block B_i, we determine a value for k, which we call k_i. The k_i's in the figure are 3, 4, 4, 5, 5, 5,

This work was supported by U. S. Army Research Office Grant DAAH004-96-1-0255.

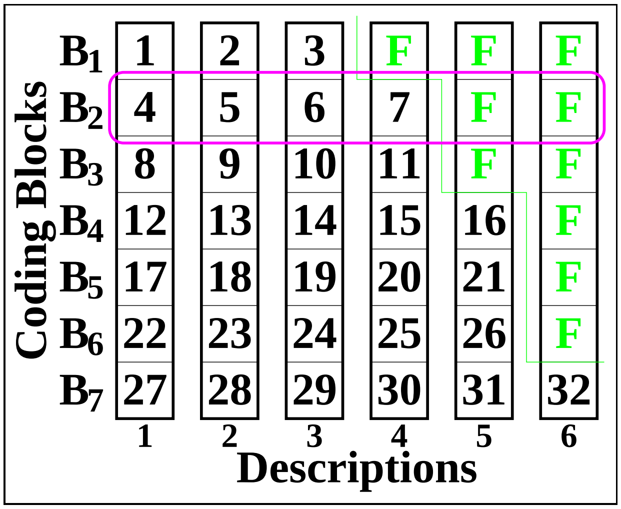

Figure 1: Each of N columns is one description, while each of the rows is an independent Reed-Solomon code block. The first 32 bytes of source coder output (numbers 1-32) and ten bytes of FEC (F) are shown.

and 6; the number of redundancy bytes for each code block is conversely 3, 2, 2, 1, 1, 1, and 0. If three descriptions are received, only block B_1 can be decoded. If four descriptions are received, blocks B_1 to B_3 can be decoded; if five descriptions are received, blocks B_1 to B_6 can be decoded; and if all six descriptions are received, blocks B_1 to B_7 can be decoded.

In Figure 2, we show which parts of the data stream can be recovered when two descriptions are lost and four are received correctly. In this case, the first three coding blocks can be recovered since they use an RS code with a k of four or less. Bytes 1–11 of the source coder output are guaranteed to be recovered. [1]

We use the fact that a progressive source coder produces an output in which information important to image quality is emitted first, followed by successively less important information. If the output of the source coder is used first to fill block B_1, then block B_2, and so on, the important information will be in blocks with small i and small k_i (heavily protected), while less important information will be in blocks with large i and large k_i (lightly protected). Note how the first 32 bytes of the source coder output fill the blocks in Figure 1, and how the prefix of the output increases as more descriptions are received. In this paper, we use the progressive SPIHT [13] algorithm with arithmetic coding to compress the data and the ULP assignment algorithm of [10] to determine a value of k_i for each i.

[1] We note that byte 12 could also be recovered when systematic RS codes are used, but this effect is negligible so we do not consider it in the remainder of this paper.

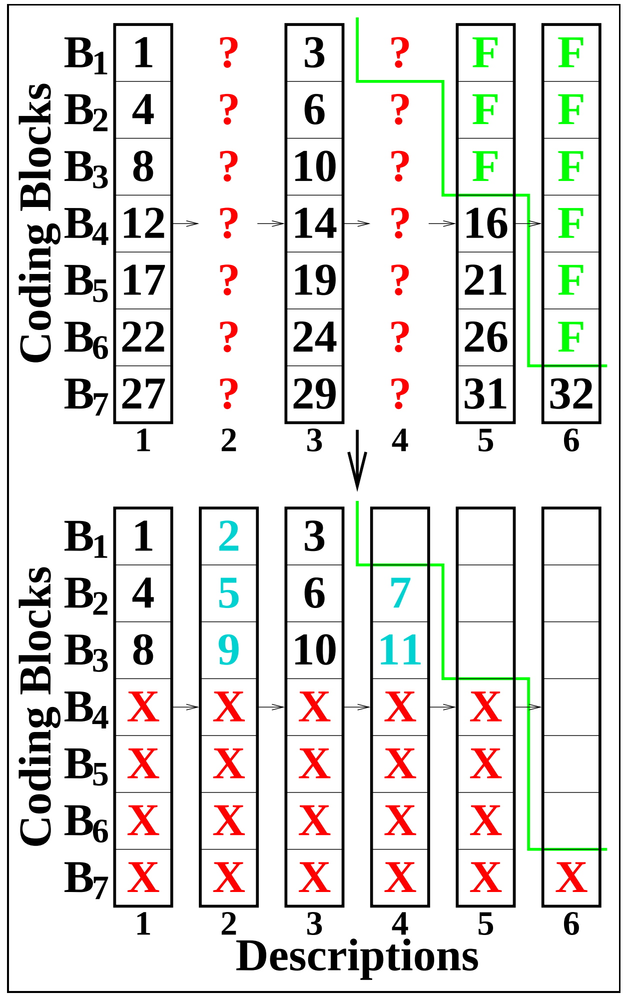

Figure 2: An example of the data recovery process in Unequal Loss Protection.

3. Multiple Description Characteristics

An encoding generated by the methodology that we have presented has a number of characteristics that are well suited to the generalized MD problem. We consider each in turn.

- **Efficient Source Coding.** MD-ULP uses unmodified SPIHT with arithmetic coding to compress the image data, so we suffer no penalties for using inefficient coding techniques.

- **Source Coder Upgradability.** Because MD-ULP can use any progressive source coder, the SPIHT algorithm that we currently use can be replaced by more efficient algorithms as they are developed.

- **Balanced Multiple Description Coding.** Each description is just as important to the final image quality as any other, resulting in deterministic image quality that is affected only by the number of descriptions that are received. MD-ULP is the first system to make this guarantee.

- **Quantifiable Overhead.** The additional redundancy is distinct from the source data, so the cost of having a robust encoding can be quantified.

- **Channel–Optimized Redundancy.** The ULP assignment algorithm can optimize the expected PSNR for a given set of expected channel conditions. Those conditions are specified by a probability mass function (p.m.f.), so MD-ULP accomodates any loss model that can be expressed as a p.m.f. This could be a uniform loss model, a complex mathematical model, or even an estimate derived from measurements of a real channel.

- **Distortion Measures.** The channel optimization will work for any distortion measure for which the source coder is progressive, so mean squared-error, PSNR, and perceptually weighted measures can all be used.

- **Simplicity and Modularity.** The design of MD-ULP is simple, with a modular division of tasks: the source coder can be designed without considering bit errors or channel losses and the optimization for an p.m.f. of channel conditions is independent of that p.m.f. is obtained.

4. Results

As one reference against which to compare MD-ULP, we selected unprotected SPIHT, in which the output of the SPIHT coder fills the first packet, then the second packet, etc. Note, however, that the PSNR at the receiver will fluctuate widely: when one channel fails, the intact prefix varies from zero to nine descriptions. Ignoring this variance, we derive the expected PSNR results for unprotected SPIHT from the probabilities of receiving prefixes of various length, assuming a uniform chance of channel failure and treating a zero-length prefix as a gray field.

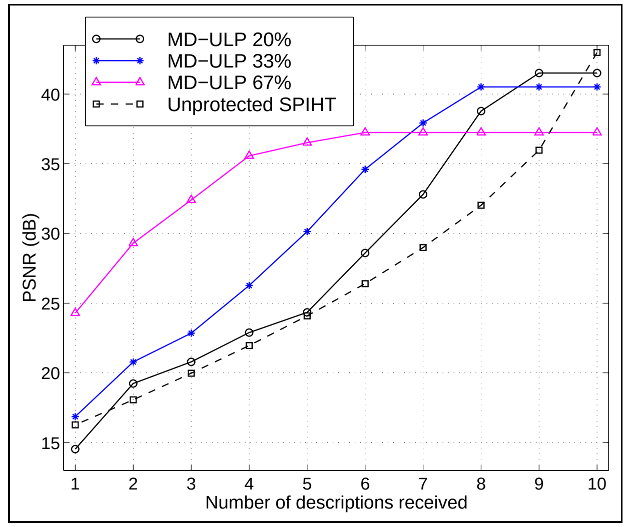

Figure 3: Demonstration of the performance of MD-ULP with 20%, 33%, and 67% of 1.25 bpp total rate used for redundancy, compared with unprotected SPIHT also at 1.25 bpp.

We present the results of MD-ULP in Figure 3, with 20%, 33%, and 67% of the total bit rate used for redundant data. As expected, when all 10 descriptions are received, unprotected SPIHT performs best, but when fewer descriptions are received, the systems with more redundancy perform better. The choice of coding parameters would thus depend on expected channel conditions. For these results, we use only deterministic decoding for our algorithm. That is, we only recover the data if the RS code is successful at decoding a block, so there is no variation in the PSNR of the received image. It is also possible to use the systematic part of blocks that fail decoding by using the received prefix to increase the expected PSNR, as we do with unprotected SPIHT. These additional data bytes would slightly improve our results, but their effect is small.

In Figure 4, we compare our algorithm with one of the first implementations of a generalized MD coder: the frame expansion system of Goyal, *et al.* [1]. Each of the three curves is about 1.25 bpp total rate, of which 20% is redundancy. The MD-ULP curve has no error bars because the reconstruction quality is deterministic. When all 10 descriptions are received, the difference in PSNR between SPIHT and JPEG is quite large, so much of the difference between the two systems is due to the choice of source coding algorithms. When a frame expansion system uses a more advanced source coder, we expect the two approaches to have more similar performance.

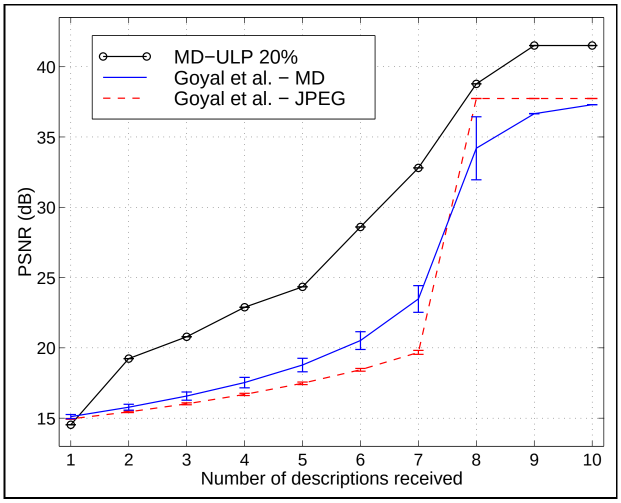

Figure 4: Demonstration of the performance of MD-ULP with the work of Goyal *et al* [1] for JPEG protected by standard FEC and their frame expansion MD method. All are for 8 descriptions at about 1.25 bpp total rate, of which 20% is redundancy.

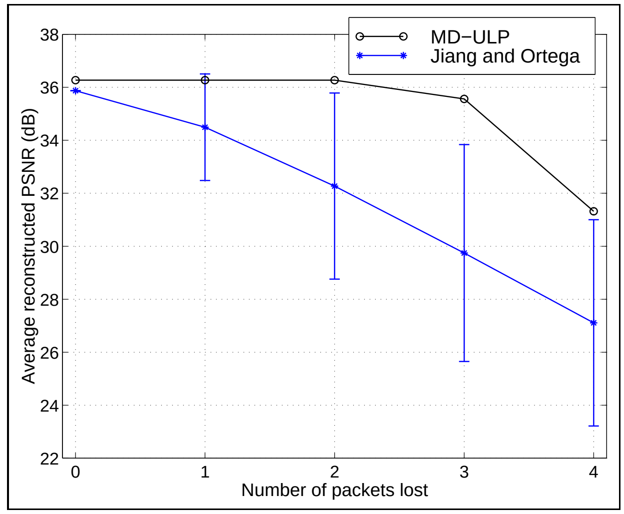

Figure 5: Comparison of the performance of MD-ULP with the work of Jiang and Ortega [6]. Both results are for 16 descriptions at 0.5 bpp total rate, of which 20% is redundancy.

Finally, in Figure 5, we compare our approach to the polyphase transform and selective quantization results of Jiang and Ortega [6], who also use the SPIHT algorithm. Each curve represents 16 descriptions at 0.5 bpp total rate, of which 20% is redundancy. Once again, MD-ULP system performs significantly better and has no variability.

5. Conclusion

We have presented results for the first application of explicit channel coding to the generalized MD problem. MD-ULP incorporates many important properties: it can be used with any progressive source coder; it generates a balanced encoding with information equally dispersed among the descriptions; it adds a quantifiable amount of redundancy; it adapts that amount of redundancy to expected channel conditions; and it can optimize for different distortion measures. These properties allow the system to gracefully improve image quality as the number of received descriptions increases. We compare our system to previously published results and show that MD-ULP surpasses them by a significant margin.

MD-ULP provides a good baseline performance comparison for future MD algorithms that perform joint source-channel coding. Furthermore, the insights that result from a study of this system can be exploited when creating a more traditional MD system. Indeed, many of these concepts were used to create a generalized MD system with competitive performance that adds redundancy during the compression process [14]. More information, related papers, and demonstration programs are available at
http://isdl.ee.washington.edu/dcl/amohr/ulp/.

6. Acknowledgements

The authors would like to thank Professor William Pearlman for the SPIHT source code and Vivek Goyal and Wenqing Jiang for providing performance results.

Appendix

In the Appendix, we explore some other characteristics of our approach that contribute to its performance and indicate features that would be useful in designing a standard joint source-channel coder.

Arithmetic coding results in approximately an 8% reduction in SPIHT coding rate compared to SPIHT without arithmetic coding near 1 bpp. If we use that improved efficiency to add 8% FEC to the arithmetic coded sequence, it could suffer up to 8% packet loss with no degradation in image quality. Clearly, maintaining source coder efficiency in a joint source-channel coding system is crucial for it to achieve good performance.

Also, our proposed system applies FEC after arithmetic coding so that the arithmetic coder can take advantage of global context when compressing the data. If a system robust to channel failure were used without explicit channel coding, its arithmetic coder would be limited to working only on the data within each description. That constraint is likely to result in decreased performance of the arithmetic coder.

In addition, an MD system combining an (N, k) RS code with a state-of-the-art source coder is in some sense optimal: no other system can exceed its performance when exactly k of N descriptions are received. (Informal proof: If another MD system could yield better performance when some size-k subset S of the N descriptions is received, then that subset S would comprise a better source coder than the one used in the RS–based system. We could then replace the state-of-the-art source coder with the one that generated S and match its performance when exactly k descriptions are received.) Of course, this proof indicates nothing about performance when the number of descriptions received is other than k, and it is this fact that we suspect will allow joint source-channel coders with comparable performance.

7. References

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