RATE-CONSTRAINED ADAPTIVE FEC FOR VIDEO OVER ERASURE CHANNELS WITH MEMORY

Shirish S. Karande and Hayder Radha
ECE dept, Michigan State University, email: {karandes, radha}@egr.msu.edu

ABSTRACT

Current adaptive FEC schemes used for video streaming applications alter the redundancy in a block of message packets to adapt to varying channel conditions. However, for many popular streaming applications, both the source-rate and the available bandwidth are constrained. In this paper, we present FEC codes that can adapt in real-time to provide higher source-packets recovery without changing the FEC block (*N*, *K*) pair constraint. The FEC *code profile* is changed as function of the number of losses to facilitate an improved data recovery even under severe channel conditions (e.g., number of losses within an *N*-packet FEC block is larger than *N*–*K*). We present a feedback based adaptive FEC scheme, which can adapt in a rate-constrained manner. We also illustrate the utility of this scheme for video streaming applications by analyzing the results of extensive video simulations and comparing our performance to adaptive Reed Solomon FEC schemes. We consider a variety of video sequences and use actual packet traces from WLAN (802.11b) and wired Internet environments. Comparison between the two schemes is conducted on the basis of message packet recovery, PSNR, model based perceptual evaluation and visual subjective evaluation. It is shown that the proposed scheme can significantly improve the video quality and in particular reduce the jerkiness in the received video.

1. INTRODUCTION

Low-delay constraints of realtime video over unreliable networks made FEC schemes ubiquitous in many multimedia applications. Moreover, due to the time varying nature of Internet sessions, adaptive FEC schemes have been explored in recent years (e.g., [1]). Most of the current adaptive schemes depend on changing the redundancy in an FEC block by changing the source and/or channel-coding rate. However in many realistic scenarios the source-coding rate cannot be changed in real-time (e.g., streaming of pre-coded non-scalable video or the base-layer of a scalable stream; and in the absence of complex source transcoding operations). In addition, the FEC redundancy cannot be increased beyond a threshold due to bandwidth constraints. Given these constraints, under severe channel conditions, and in particular when the number of losses (*L*) in an FEC block (*N*, *K*) is greater than the maximum allowable redundancy (*N*–*K*), the popular Reed-Solomon (RS) erasure recovery codes cannot recover any lost message packets. This highlights the need for adaptive erasure codes that can recover lost message packets while maintaining the FEC block (*N, K*) parameters.

In this paper, we develop *adaptive* FEC schemes that could change the FEC *code profile*[1] without changing its rate (*K*/*N*) and block-length (*N*). Our approach is based on "partial recovery codes", known as Partial Reed Solomon Codes (PRS) [2], [3], [4] that have been introduced recently. Hence, in section 2.A we give a brief introduction to PRS codes. These codes were first presented and analyzed for Binary Erasure Channels (BEC) in [2] and there utility for video streaming over BEC was discussed in [3]. However, the utility and design of these codes for *adaptive* FEC schemes *with feedback* for actual channels *with memory* is as yet unexplored. Thus in section 2.B we identify good partial recovery codes, which we employ to design our rate constrained adaptive FEC scheme. In Section 3 we present the feedback setup for the adaptive FEC schemes and present the proposed PRS based rate-constrained adaptive FEC. In Section 4 we compare the packet recovery capability of the RS and PRS based adaptive FEC schemes for actual channel traces [5], [6]. In Section 5 we compare the performance in terms of video quality. It is shown that the PRS based adaptive FEC significantly improves the perceived video quality and in particular reduces the jerkiness or the unnatural motion in a picture sequence. Finally in Section 6 we summarize our conclusions.

2. PARTIAL REED SOLOMON CODES

A. Background

For a given real-time pair constraint (*N*, *K*), we denote a general PRS code of order s by (N, K, Λ_s) . Here Λ_s represents a $2\times(s+1)$ matrix given by $\begin{bmatrix} N_1\cdots N_{s+1} \\ K_1\cdots K_{s+1}\end{bmatrix}$. Thus

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[1] Here, the *code profile* represents a partition of the FEC block (*N, K*) into *multiple* FEC sub-blocks (or sub-codes) as explained later. In a traditional RS code, there is a *single* FEC block. Our adaptive scheme is based on modifying the number and size of the FEC sub-blocks while maintaining the desired rate *K*/*N*.

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Λ_s gives an s-partition on the set of parity symbols and a $(s+1)$-partition on the set of message symbols. Figure 1 shows an example of such a code with $s = 2$. The code is designed such that, $\forall\ i \in [1, s]$, the pair (N_i, K_i) forms an RS-subcode and the K_{s+1} number of message symbols are transmitted without any protection. The interested reader is referred to [2], [3], [4] for further details about PRS codes and their construction.

It is very important to note that under PRS, *all* message packets are considered *equally important*. This includes the unprotected packets. (Although in practice, the source packets may be of different importance.) Hence, the PRS partition does NOT represent (and is not induced by) a prioritized scheme [7] or unequal-error protection. A PRS code achieves partial recovery and improved message-throughput (when compared to a traditional RS code) despite its treatment of *all* message packets as *equally-important*. Meanwhile, the PRS codes' performance (e.g, in terms of PSNR video) could be enhanced further when combined with a prioritized scheme. In this paper, we do not incorporate any prioritized scheme with our adaptive PRS-based FEC codes, and yet we achieve significant improvements over adaptive RS codes.

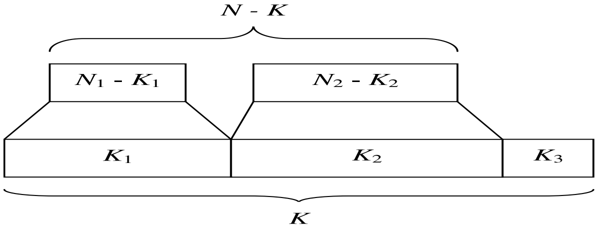

Figure 1 An order 2 PRS code

A. Design for adaptive FEC

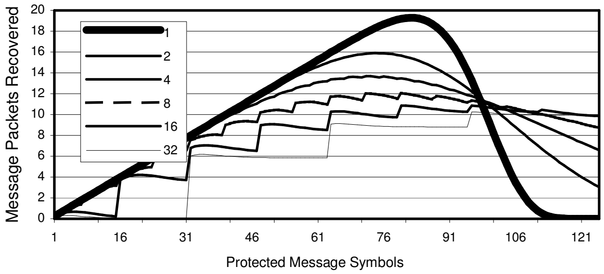

Figure 2 Partial recovery performance of PRS codes (L=40).

We denote the average message throughput due to a single component of the code graph, i.e. a single sub-code by $\rho(N_i, K_i)$. Thus the average total message throughput of an order s PRS code is given by $\tau_m = \sum_{i=1}^{s+1} \rho(N_i, K_i)$. If the number of erasures in a given codeword is equal to L then the average message throughput for is denoted by $\tau_m(L) = \sum_{i=1}^{s+1} \rho(N_i, K_i, L)$. The message throughput for a given L due to the subcode i can be expressed by the following equation:

$$\rho(N_i, K_i, L) = \frac{\mathrm{T}_1 + \mathrm{T}_2}{\mathrm{T}_3}, \text{ where } \mathrm{T}_3 = K \cdot \binom{N}{L},$$

$$\mathrm{T}_1 = \sum_{j=\max(0, N-N_i-L)}^{\min(N_i-K_i, L)} K_j \cdot \binom{N_i}{j} \cdot \binom{N-N_i}{L-j} \text{ and}$$

$$\mathrm{T}_2 = \sum_{j=\min(N_i-K_i, L)}^{\min(N_i, L)} \left(\frac{K_i}{N_i}\right) \cdot (N_i - j) \cdot \binom{N_i}{j} \cdot \binom{N-N_i}{L-j}$$

Here T_3 represents the total number of message packets transmitted, T_1 represents the message packets received from subcode i when there is no decoding failure and T_2 represents the message packets received on account of a decoding failure in subcode i. In the next section we will present the feedback setup for our adaptive FEC scheme where the code profile is changed based on the number of packet drops. Thus we will identify a set of PRS codes that maximizes $\tau_m(L)$. We will use this set for the PRS based adaptive FEC scheme.

To identify good partial recovery codes, we consider the performance of a set of semi-regular PRS codes with N=160 and K=128. In this set, $\forall$ order s PRS code, $\forall i \in [1, s]$, both N_i and K_i are maintained constant. Thus all the partitions, except for the unprotected part, contain equal numbers of message and redundancy packets. Figure 2 exhibits the performance of PRS codes from this set for L=40 (which in this example is equivalent to 32 message packets being dropped). As the number of erasures is greater than the redundancy, an RS code cannot recover any of the dropped packets. However, it can be seen that all PRS codes provide partial recovery of information. The degree of information recovery is a function of the code profile. It was shown in [2] that the optimal PRS code for a BEC is a PRS-1 code. Figure 2 depicts that even for the case where the number of losses are known, the best information recovery is offered by a PRS–1 code. Extensive simulations have failed to provide a counter example. However, further analysis from a coding theory perspective is outside the scope of this paper. Thus, in this paper we focus our analysis and design to PRS-1 codes, which are, in turn, employed for partial recovery in rate-constrained adaptive environments.

3. FEEDBACK AND CODE ADAPTION

An example of a reactive feedback system is shown in figure 3, where the redundancy is designed as a function of the number of losses. When the number of losses is less than the maximum allowable redundancy, the behavior and performance of the RS and PRS based adaptive schemes is exactly identical. As RS codes suffer from a loss threshold, thus an incorrect estimate of the number of losses can severely hamper the performance of RS based adaptive schemes. Hence in order to provide an advantage to adaptive RS codes, we make two assumptions. First, the number of losses (*L*) does not change abruptly, and hence, the loss estimate provided by the feedback system is accurate. Further, two (virtually separate) channels are used: one for the message packets and the other for the parity packets. Losses are encountered in the message channel but not in the parity channel. If the number of message losses is greater than the maximum allowable redundancy an adaptive RS code cannot recover any information (given the maximum (*N*, *K*) constraint). However, PRS based scheme maintains the rate constraint and changes the code profile by altering the size of the unprotected data segment as a function of the losses. This facilitates a partial recovery of information and as shall be shown in the subsequent sections, is responsible for maintaining video quality under severe and bursty channel conditions.

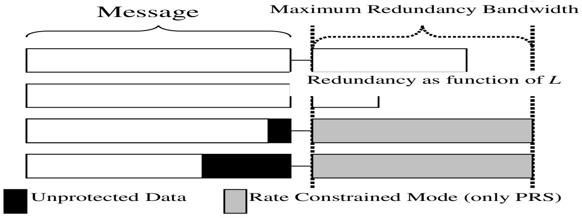

Figure 3 Architecture of RS and PRS based adaptive FEC

4. PACKET RECOVERY ANALYSIS

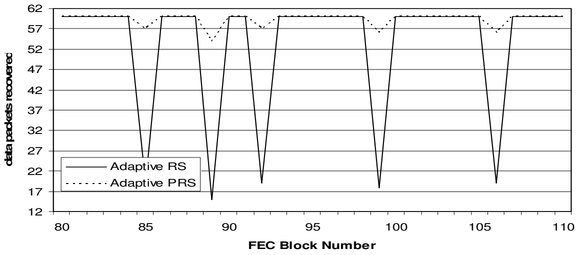

Figure 4 Message packet recovery performance over 5.5 mbps

In this section we present the packet recovery capability of the considered adaptive schemes. Figure 4 shows a snapshot of the performance of the adaptive FEC schemes with 60 message packets in each FEC block and with a bandwidth constraint which allows a maximum of 40 redundant packets in each block. The results in Figure 4 are obtained by simulating transmission over an actual 5.5Mbps 802.11b WLAN packet trace [5]. It can be observed that, though the lowest coding rate (i.e. 0.6) is well below the average packet drop probability of the trace, there exist instances when the number of losses in a single block can be very high. Under such scenarios the RS based adaptive FEC scheme is unable to recover any information, however the PRS based adaptive FEC scheme can still provide significant amount of information recovery. Similar performance was obtained for 11mbps [5] and Internet traces provided in [6].

5. VIDEO EVALUATION

We used an H.264/JVT video software codec with packet loss resilience capabilities to perform our video evaluation. Figure 5 shows a PSNR comparison of the end-receiver video quality of a robust 1.6 Mbps 30Hz stefan sequence transmitted over a 5.5mbps channel. It can be seen that for GOPs hit by severe packet drops, the RS based adaptive FEC scheme provides a very poor video quality, whereas the PRS based FEC scheme maintains the video quality high for a longer duration[2].

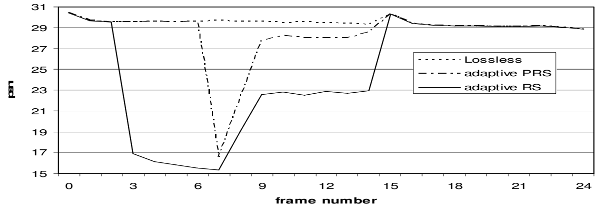

Figure 5 PSNR based comparison (5.5mbps 802.11 b WLAN)

Figures 6 and 7 provide a subjective comparison of the performance of RS and PRS schemes. Figure 6 shows picture frames for a 30Hz carphone sequence coded at 194kbps, simulated over an Internet session. The trace used for simulation was obtained from [6] and had a packet drop probability of less than 0.16. The FEC pair constraint used was (20, 15). Figure 6 shows that for the rs based adaptive scheme the video was frozen from frame 354 to 357, in addition for a period of an entire GOP (15) the distortion in the RS based scheme rendered the human face unrecognizable. However, the PRS based scheme maintains the facial distortion in tolerable limits. Similar observations were made for simulations over WLAN traces. A 30Hz stefan sequence coded at 2.62 Mbps was transmitted over 5.5 Mbps channel, which had a packet drop probability of less than 0.25. The FEC pair constraint used was (100, 60). Figure 7 shows that for the RS based scheme the picture is frozen from frame 2 to 7. Even after that the level of distortion in the RS based scheme is higher. Such performance was very typical for a variety of sequences under varied channel conditions. This "loss of action" significantly compromises the video viewing experience, especially for sports sequences. Thus, one of

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[2] All the error concealment features have been turned off to avoid their influence on the interpretation of the performance results. For further simulations all the error robustness is reduced to an absolute minimum, it should be noted that existence of any error resilience improves the relative performance of PRS.

the most significant advantages of a PRS-based adaptive FEC scheme from video perception perspective is reduction of jerkiness or unnatural motion during severe channel conditions. This can be further illustrated by using the Video quality meter [7], which conducts a model based perceptual evaluation of video sequences. Table 1 illustrates the results of such a test. It can be seen that for moderately affected video sequences, secondary artifacts in RS schemes are almost reduced to perceptually undetectable level by PRS schemes, while for severely affected video sequences primary artifacts are reduced to secondary artifacts.

FEC	*Rate*	Sequence	fps	bitrate	Jerkiness
lossless	-	stefan	30	562.8 kbps	8%
adaptive-prs	0.6	stefan	30	562.8 kbps	15%
adaptive-rs	0.6	stefan	30	562.8 kbps	35%
lossless	0.7	stefan	15	406.8 kbps	5%
adaptive-prs	0.7	stefan	15	406.8 kbps	54%
adaptive-rs	0.7	stefan	15	406.8 kbps	95%

Table 1 Television model based perceptual evaluation, 100% = perceived as a primary artifact by all viewers, 50% = perceived as a secondary artifact, 0% = artifact not perceived

6. CONCLUSION

In this paper we presented a mechanism to adapt a code without changing its block-length or coding rate. Such codes can be utilized to design rate constrained adaptive FEC schemes. It was shown that these rate constrained adaptive schemes can significantly improve the packet recovery capability. With the help of extensive video simulations over varied number of realistic channel scenarios it was shown that PRS based schemes do indeed significantly improve the end-receiver video quality during poor channel conditions.

7. REFERENCES

[1] J. C. Bolot, S. Fosse-Parisis, and D. Towsley, “Adaptive FEC-based error control for Internet telephony,” Proc. of IEEE INFOCOM '99, March 1999.

[2] S. S. Karande and H. Radha, “Partial Reed Solomon Codes,” IEEE Information Theory Workshop, April 2003.

[3] S. S. Karande and H. Radha, "A New Family of Channel Coding Schemes for Real-Time Visual Communications," IEEE (ICME), July 2003.

[4] S. S. Karande and Hayder Radha, “Partial Reed Solomon Codes for Erasure Channels,” under submission to IEEE Trans. Inform. Theory.

[5] S. A. Khayam, S. S. Karande, H. Radha, and D. Loguinov, "Performance Analysis and Modeling of Errors and Losses over 802.11b LANs for High-Bitrate Real-Time Multimedia," Signal Processing: Image Communication, August 2003.

[6] http://standard.pictel.com/ftp/video-site/0109_San/VCEG-N79r1.doc.

[7] A. Albanese, J. Blomer, J. Edmonds, M. Luby, and M. Sudan, "Priority encoded transmission," IEEE Trans. Inform. Theory, vol.42, no.6, pp. 1737-1744, Nov. 1996.

[8] http://www.its.bldrdoc.gov/n3/video/vqmsoftware.htm

Figure 6 Comparison of carphone over (wired) Internet, left column: frames 354, 357, 370 from a rs-based scheme, right column: frames 354, 357, 370 from a prs-based scheme.

Figure 7 Comparison of stefan over 5.5 Mbps WLAN, left column: frames 2, 7, 8 from a rs-based scheme, right column: frames 2, 7, 8 from a prs-based scheme.