An Optimal Selective Protection Scheme for Scalable Video Coding

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Abstract

The fundamental problem of selective protection scheme for encoded bitstreams is to find an efficient algorithm to select the set of frames required to be encrypted that can maximize protection effect with the minimum amount of protected data is required. In this paper, we propose an optimal selective protection scheme for SVC bitstreams by protecting the best combination of frames for selective protection in the sense that the amount of data required for protection is minimized and the resulting visual quality degradation is maximized. The selection of the frames to be encrypted is done by first expressing R-Q (protection rate - visual quality) relationship with Lagragian cost model. The experimental results show that, compared to protecting SVC bitstreams layer by layer, the proposed scheme gives superior performance in terms of protection effectiveness due to its better selection of frames for protection given protection bit budgets.

1. Introduction

Dependency coding characteristics of H.264|MPEG-4 Part 10 Advanced Video Coding (AVC) [1] and the H.264 Scalable Extension|MPEG-4 Scalable Video Coding (SVC) [2] can best be utilized in selective protection of bitstreams. By utilizing the coding dependency in encoded bitstreams, more effective encoded frame data can be selected and protected which can maximally affect the reconstructions of the following frames which refer to the protected frames.

In this paper, we propose an optimal frame level selective protection scheme for SVC bitstreams. The selection of the effective frames for encryption (protection) is constrained by a protection bit budget (i.e., the allowed amount of data for encryption) which is set before the protection is executed. Without an efficient algorithm, the overhead complexity to determine the best combination of frames for encryption is exponential to the number of frames in the bitstreams to be encrypted, that is 2^n, where n is the number of frames. In the proposed scheme, we employ Lagragian optimization to model a joint cost of both protection bit amount and resulting visual quality so that the solution to the optimal protection problem can be solved by finding the optimal protection rate and visual quality (R-Q) curve. By doing so, we successfully reduce the overhead complexity from exponential to linear.

The rest of this paper is organized as follows: In Section 2, we present the proposed optimal protection scheme with the optimization framework with optimal R-Q curves for protection. The optimal R-Q curve is used by the proposed optimal selective protection scheme to select the best combination of frames for effective protection; In Section 3, we present the experimental results and analyze the performance of the proposed optimal selective protection scheme; and in Section 4, we conclude this paper.

2. Proposed Selective Protection Scheme

The selection of effective frames for protection can be formulated as an optimization problem to find the best combination of frame c^* from a set of frames $F = \{f_0, f_1, \cdots, f_{n-1}\}$ from input SVC bitstream to be encrypted that minimizes the average visual quality of the reconstructed frames for an SVC bitstream given a target bit budget B for protection. The problem can be formulated in a constrained model as follow:

$$J(c_i|\lambda) = Q(F \mid c_i) + \lambda R(c_i) \tag{1}$$

where $c_i = \{f_0, f_1, \cdots, f_{n-1}\}$ is the i-th combination of frames in F. J is called the Lagrangian cost and λ is a Lagrangian multiplier with $\lambda \geq 0$. The solution to the optimal selective protection problem can be found by finding the minimum cost for all the possible combinations of frames to be protected as follow:

$$J(c^*|\lambda) = \arg\min_{0 \leq i \leq 2^n - 1} [Q(F \mid c_i) + \lambda R(c_i)] \tag{2}$$

Figure 1 shows an R-Q scatter plot of operation points (OPs) for all possible combinations of protected frames in the first GOP (8 frames/GOP) of an SVC bitstream for the Foreman sequence of QCIF. The SVC bitstream of the Foreman sequence is encoded by H.264/SVC JSVM version 9.1 [3] with QP = 22. The x-axis indicates the relative amount of protected bits normalized between 0 and 1, while the y-axis indicates the visual quality in SSIM. Each point in the R-Q scatter plot corresponds to an operating point (OP) for the pair of a normalized amount of protected bits and the resulting average visual quality for the reconstructed frames of the bitstreams when the combination of the selected frames is protected.

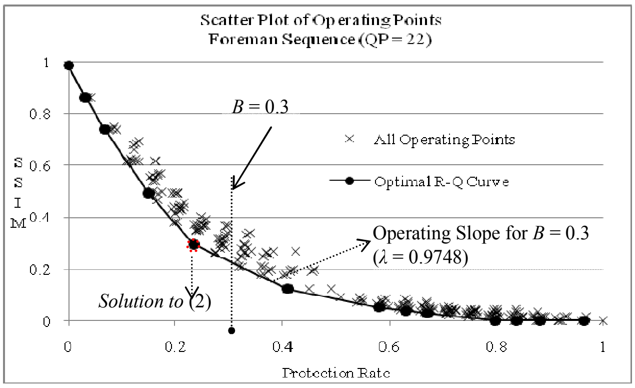

Figure 1: A scatter plot of OPs and optimal R-Q curve for the combinations of selectively protected frames

As depicted in Figure 1, the set of all OPs which are associated with all possible combination of frames to protect F can be regarded as a convex set and the set of OPs that satisfy (2) is referred to as the OPs connected in the solid line curve that eventually forms the lower convex hull of the set of all OPs. Therefore, the solution to the optimal protection problem in (2) can be found by finding the OPs that constitute the lower convex hull which is regarded as the optimal R-Q curve for protection. OP B (i.e., the OP in the dotted circle) in Figure 1 is the solution to the protection optimization problem when the protection bit budget is set to $B = 0.3$.

3. Experimental Result and Analysis

We have implemented the proposed RQDSP scheme into SVC reference software, JSVM 9.1 and compare its performance against layered protection (LP) scheme [4]. Both schemes are tested on the same PC and are tested for the same test sequences that are encoded under the common encoding configuration for various quantization values and various input SVC bitstreams.

The performance improvement by the proposed scheme over the LP scheme is due to the fact that better selection of frames for protection can be made based on the estimated optimal R-Q curves for given protection bit budgets. Figure 2 shows the reconstructed frames for the Soccer bitstream protected by the LP scheme in Figure 2(a) and by the proposed scheme in Figure 2(b) for protected bit budget of 0.4. Both schemes require almost the same amount of protected bits but choose different combinations of frames for selective protection. For example, the LP scheme can only protect the 0^{th}, 8^{th}, 16^{th}, and 24^{th} frames of the Soccer bitstream. On the other hand, the proposed scheme does not choose the 8^{th} and 24^{th} frames for protection because protection to the 0^{th} and 16^{th} frames would already cause a severe effect of visual quality degradation to the 8^{th} and 24^{th} frames. Instead, the protection bit saving from not protecting the 8^{th} and 24^{th} frames can be then used to protect the 12^{th}, the 28^{th}, and the 30^{th} frames. Therefore, although protected bit amounts of both schemes are about the same (i.e., 0.380 and 0.378 for the LP scheme and the proposed scheme, respectively), the effects on the visual qualities for the protected bitstreams are significantly different.

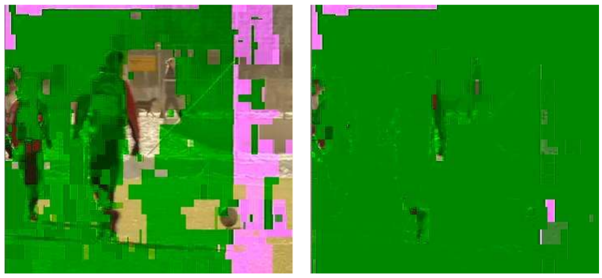
(a). R = 0.38; Q=0.438 (b). R=0.378; Q=0.031

Figure 2: Reconstructed frames from SVC bitstreams protected by (a). The LP scheme; (b). The proposed scheme

4. Conclusion

In this paper, we present an optimal selective protection scheme for SVC bitstreams The proposed scheme efficiently find the best combination of frames that should be encrypted which maximizes visual quality degradation of the protected SVC bitstreams for given protection bit budgets. The major contribution in this paper is the algorithm to determine the optimal R-Q curve for protection which can be used to find the best combination of frames for protection.

The experimental results show that the proposed optimal selective protection scheme is more effective in protection, compared to layer-by-layer protection. The superior performance of the proposed optimal selective protection scheme is attributed to its better selection for the combinations of selectively protected frames based on the optimal R-Q curves for given protection bit budgets.

References

[1] T. Wiegand, G. J. Sullivan, G. Bjontegaard, and A. Luthra, "Overview of the H.264 / AVC Video Coding Standard," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 13, no. 7, pp. 560-576, July 2003.

[2] H. Schwarz, D. Marpe, and T. Wiegand, "Overview of the Scalable Video Coding Extension of the H.264/AVC Standard," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 17, no. 9, pp. 1103-1120, Sept. 2007.

[3] Joint Scalable Video Model (JSVM) version 9.1: Available: http://ip.hhi.de/imagecom_G1/savce/downloads/SVC-Reference-Software.htm.

[5] T. Stutz and A. Uhl, "Format-compliant Protection of H.264/AVC and SVC" *Proceeding of the10th IEEE International Symposium on Multimedia*, Berkeley, CA, pp. 446-45, Dec. 2008.