A Selective Protection Scheme for Scalable Video Coding Based on Dependency Graph Model

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Abstract

In this paper, we propose an efficient and effective selective protection scheme to SVC that exploit the propagation of protection effect by protecting significant frames that can give the maximum visual quality degradation. We model SVC dependency coding structure as a directed acyclic graph which is characterized with an estimated visual quality value as the attribute at each node. The estimated visual quality is calculated by using our model based on the proportions of intra- and inter-predicted MBs, amounts of residual, and estimated visual quality of reference frames. The proposed selective protection scheme traverses the graph to find optimal protection paths that can give maximum visual quality degradation. Experimental results show that the proposed selective protection scheme reduces the required number of frames to be protected by 46.02% compared to the whole protection scheme and 27.56% compared to the layered protection scheme.

1. Introduction

The H.264 Scalable Extension / MPEG-4 Scalable Video Coding (SVC) [1] provides a representation of coded bitstream that is highly adaptable to various requirements on user preferences, terminal capabilities, and varying network conditions in a wide range of use case scenarios. While this high adaptability feature encourages adoption of the SVC to various multimedia applications, it is important to ensure that SVC bitstreams be secured from unauthorized access. Because it is difficult to encrypt the whole SVC bitstreams (i.e., the whole protection) due to their vast amount of coded data and also such protection will strip adaptability features of SVC. Therefore, there is a need to invent an effective and efficient protection scheme that avoids the whole protection but selectively protects parts of encoded bitstreams that can give satisfactory levels of protection and preserve SVC adaptability feature at the same time.

The SVC encodes frames into one or more scalability layers where the frames in higher scalability layers are encoded by referencing to the frames in their lower scalability layers as well as the same scalability layers. The lowest layer in each scalability layer is called the base layer whereas the higher layers are called the enhancement layers. The SVC can provide scalable bitstreams in terms of spatial, temporal, and quality scalabilities. Figure 1 illustrates an example of a dependency coding structure of SVC with two spatial and three temporal scalability layers. F(0,0,0) represents the frame that belongs to spatial base layer (SBL), temporal base layer (TBL), and quality base layer (QBL) whereas

F(1,2,0) is the frame that belongs to the first spatial enhancement layer (SEL-1), the second temporal enhancement layer (TEL-2), and the QBL. Within such a dependency coding structure, if a frame is protected, other frames may refer to the protected frame as their reference frame so that visual quality degradation occurs in their reconstructed frames. For example, if protection is applied to F(0,0,0), the effect of this protection will propagate to the reconstructions of F(0,1,0), F(0,2,0) and F(1,0,0). Then, it may continue propagating to the reconstruction of F(1,1,0), and further to the remaining frames in the structure.

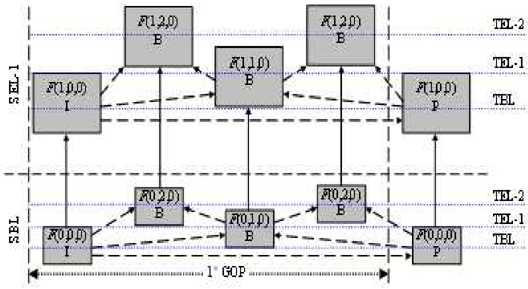

Figure 1. A spatial and temporal hierarchical structure of SVC bitstream

In this paper, we propose a selective protection scheme for SVC bitstreams that exploits the dependency coding structure of SVC to maximize the protection effect with the number of selectively protected frames to a minimum, thus leading to lowering computational complexity for protection. The dependency coding structure of an SVC bitstream is modeled as a dependency graph by using a directed acyclic graph. In addition, we also propose an algorithm to search the dependency graph for an optimal path by selecting a set of frames for protection that gives the highest visual quality degradation. Each vertex of the dependency graph has an attribute value that represents visual quality of the corresponding encoded frame. The visual quality is estimated from the proportion of MB types (intra-/inter-predicted), amounts of residues and estimated visual quality of source vertices. The proposed selective protection scheme is independent of any specific encryption algorithm, but in this paper, we use the AES encryption tool with a key in 256-bit length to protect the selected frames.

This paper is organized as follow: in Section 2, we describe the system architecture of our protection system, the dependency graph model, and the searching algorithm for optimal protection path. In Section 3, we present our experimental result that show the effectiveness our the proposed protection scheme compared to the whole protection scheme. Finally, the we conclude our paper in Section 4.

2. The Proposed Selective Protection Scheme for SVC Bitstreams

A. System Architecture

Figure 2 shows the block diagram of the proposed selective protection scheme. The system contains three parts: an SVC Dependency Analyzer, a NAL Unit Buffer and a NAL Unit Protector. During the encoding process, the SVC Dependency Analyzer collects the information of coding types of MBs, the ratios of Intra-MBs, IntraBL-MBs, and Inter-MBs, and the amount of residues for the frames that are being encoded by the SVC Encoder. Then, it constructs a dependency coding structure as a directed acyclic graph which is described in the following subsection. Based on this graph, the proposed selective protection scheme selects an optimal set of frames for protection. A NAL unit buffer is used to temporarily store NAL units outputted from an SVC encoder before the decision is made on which NAL units must be protected. The selected NAL units are then encrypted by the NAL Unit Protector.

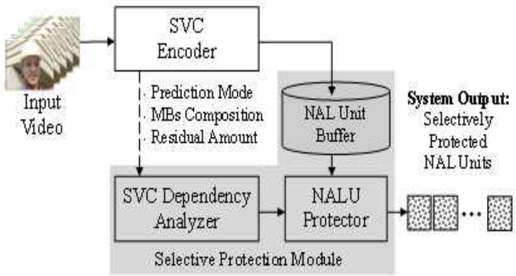

Figure 2. A block diagram of the proposed scheme

B. Dependency Graph Model and Optimal Protection Path

Dependency structure of an SVC bitstream is modeled by as a directed acyclic graph $G=(V,E,Q)$, where V is a set of vertices for which each vertex represents an encoded frame in an SVC bitstream, E is a set of edges and Q is a set of estimated visual qualities such that every vertex v_i has an attribute of estimated visual quality q_i. An edge e_{ij} is directed from vertex v_i to vertex v_j which indicates the coding dependency relation between v_i and v_j such that the frame associated to v_j is encoded by referring to the frame associated to v_i.

Based on the graph structure, we design a searching algorithm for an optimal protection path with corresponds to the optimal set of frames that gives the maximum visual quality degradation to the corresponding SVC bitstream. We define a set of protected vertices V_P and a set of unprotected vertices V_u, where there is no common member between V_P and V_u and V_P and V_u are subset of V. At the beginning of searching the dependency graph, V_P is set to an empty set and V_u contains all vertices of the dependency graph. The graph searching starts from the root vertex. After that, the next vertex to be protected is vertex v_s from V_u which fulfills the following two requirements: (1) If V_P is not an empty set, there should be at least one vertex in V_P that is in a distance equal to 1 from v_s; and (2) Protection of the frame associated to v_s should yield the estimated visual quality of the remaining unprotected vertices to a minimum in the graph. Once v_s is selected for protection, it should be moved from V_u to V_P as one of the vertices in optimal protection paths. The frame that is represented by v_s shall be protected and its attribute is set to one of the predefined default values of 0.0005 for *QCIF,* 0.002 for *CIF* and 0.008 for *4CIF* which are found experimentally to give no visible information. After that, the attributes of all successor vertices of v_s in V_u must also be updated in breadth-first order. The updates is done as by setting the attribute to:

$$(r^{Intra})^{1.5}+(r^{Inter}*(0.118+0.706q^{Ref}-0.1315q^{Res}-3.6068q^{Ref}q^{Res}+0.1739\,(q^{Ref})^2+7.9075\,(q^{Res})^2))$$

where r^{Intra} denotes ratio of intra MBs, r^{Inter} denotes ratio of inter MBs, q^{Ref} denotes visual quality of reference frame, and q^{Res} denotes visual quality of residue in the frame. Note that the visual quality is measured by using Structural Similarity Index (SSIM) [2] The algorithm iterates until V_u is empty or protection to the frame associated to v_s does not give any significant visual quality degradation to the remaining unprotected vertices. Figure 3 illustrates an example of a dependency graph with searching procedure for finding optimal protection paths.

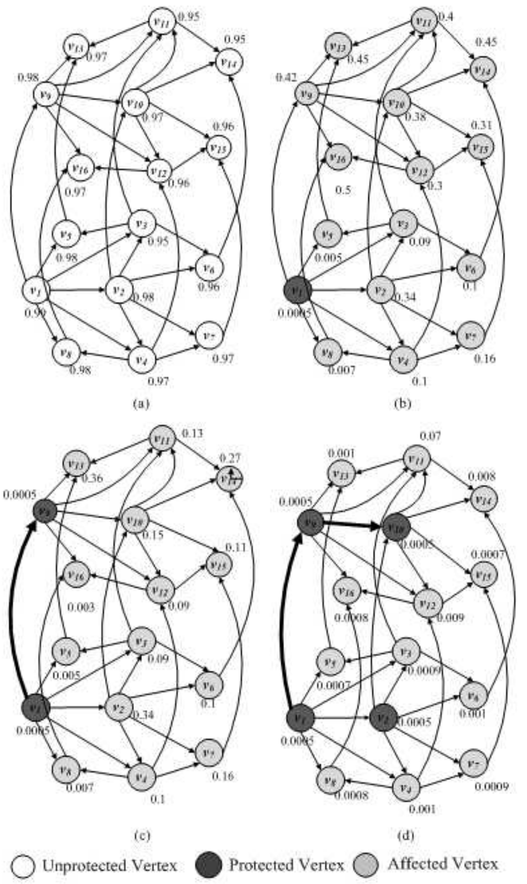

Figure 3. A example of dependency graph and search process for optimal protection path.

3. Experimental Result

To validate the performance of our proposed protection scheme, we compare the number of required frames to be protected by our proposed protection scheme to two other existing scheme: the whole protection scheme which simply protects all NAL units of input SVC bitstreams, and the layered protection scheme which protect SVC bitstreams layered by layered as described in [3]. All input bitstreams are SVC encoded bitstream with 256 NAL units each having 2 spatial layers, 4 temporal layers, and 1 quality layer. The experimental result proves that the proposed protection scheme is much more efficient and effective for it reduces the required frames (NAL units) to be protected significantly.

Table 1. Performance comparison in term of number of required frames (NAL units) to be protected between Whole Protection Scheme (WP), Layered Protected Scheme (LP), and the Proposed Protection Scheme (PP)

Sequence	# protected NAL units				
	WP	LP	PP	PP Vs. WP	PP Vs. LP
City	256	144	82	68%	43.11%
Football	256	256	182	29%	29%
Foreman	256	160	113	56%	29.6%
Ice	256	192	136	47%	29.33%
Soccer	256	192	179	30.08%	6.77%
Average Improvements				46.02%	27.56%

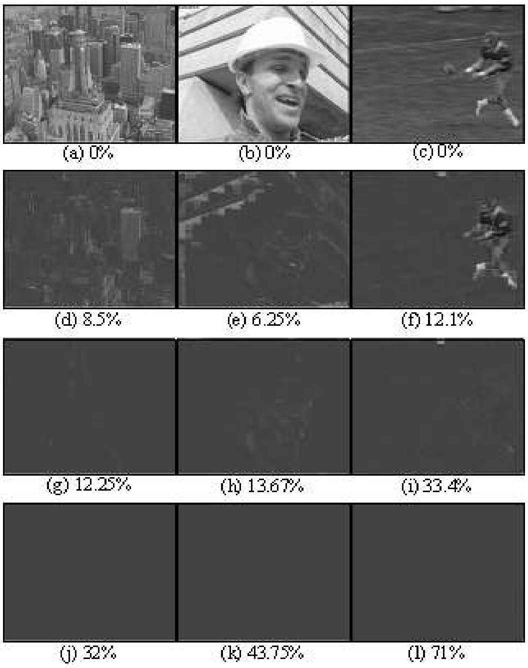

Figure 4. Reconstructed frames from selectively protected SVC bitstreams. (a)~(c) no protection. (d)~(f) weak protection is applied. (g)~(i) moderate protection is applied. (j)~(l) optimal selective protection is applied.

Figure 4 shows the visual quality degradation caused by the proposed scheme for test SVC bitstreams of City, Foreman, and Football sequences. For all test sequences, the resulting visual quality degradation becomes higher as more protection is applied on the frames. Satisfactory levels of visual quality degradation seems to be achieved by protecting about 12.25~14.84% of the whole frames for most of the test sequences except Football sequence that contains very large and complex motion and are very often encoded in Intra-MB type. In this case, more frames (about 33.4%) are required to reach a satisfactory level of visual quality degradation by protection

4. Conclusions

In this paper, we present an efficent selective protection scheme for SVC bitstreams. The proposed protection scheme only protect frames that significantly reduce visual quality of the overall input SVC bitstreams. Our experimental results show improvement in required NAL units to be protected aspect as much as 46.02% compared to the whole protection and 27.56% compared to the layered protection scheme.

References

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