Keyframe Insertion for Random Access and Packet-Loss Repair in H.264/AVC, H.265/HEVC, and H.266/VVC

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Sending low-delay live video over error-prone channels comes with packet-loss-repair and random-access challenges. Existing solutions have a negative impact on end-users with reliable connections or users that do not switch channels. To minimize this impact, the keyframe-insertion technique extends a compression-efficient normal stream (NS) with a companion stream (CS) solely consisting of keyframes [1].

This work lists the requirements to enable keyframe insertion in H.264/AVC, H.265/HEVC, and H.266/VVC. First, for keyframes in H.264/AVC and Instantaneous Decoder Refresh frames in H.265/HEVC, the Picture Order Count should be zero. Second, if there is a difference between the parameter sets (PS) of the NS and CS, then the inserted keyframe should be preceded with the PS of the CS and succeeded with the PS of the NS. Third, Temporal Motion Vector Prediction should be disabled.

The results show that the general negative quality impact is low for all evaluated codecs. However, for rare outliers, drift-error artifacts become perceptible over time (see Table 1). We found that this worst-case artifact type in H.264/AVC is caused by halfpel interpolation that slightly amplifies certain frequency components. Although this is not a perceptible problem in ordinary compression, it becomes perceptible when an error is introduced due to keyframe insertion and the filter is applied repetitively. By modifying or disabling subpel motion estimation, the quality impact is low (see last two rows in Table 1). In conclusion, this work discusses the viability of keyframe insertion in multiple compression standards to improve low-latency video distribution.

Table 1: Negative quality for **worst-case** sequence *BQSquare*.

Standard	Codec		Max. ΔVMAF				Min. frames before ΔVMAF ≥ 6			
		$QP_{NS} = QP_{CS} =$	22	27	32	37	22	27	32	37
H.264/AVC	x264		67.0	62.5	48.6	35.2	155	161	174	188
	JM		57.3	48.8	37.7	29.4	168	164	183	187
H.265/HEVC	x265		4.4	4.4	5.3	3.1	-	-	-	-
	HM		3.1	2.8	2.6	3.5	-	-	-	-
H.266/VVC	VTM		7.1	25.0	11.7	3.3	355	194	232	-
H.264/AVC	x264 - halfpel changed		3.6	2.8	2.4	2.6	-	-	-	-
	x264 - ultrafast (no subpel)		1.5	3.1	3.1	4.2	-	-	-	-

[1] G. Van Wallendael et al., "Keyframe Insertion: Enabling Low-Latency Random Access and Packet Loss Repair," *Electronics*, vol. 10, no. 6, 2021.

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