Practical SVC video streaming over partially realiable transport

by

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Master Thesis

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Abstract

Practical SVC video streaming over partially realiable transport
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Scalable Video Coding (SVC) employs layered coding techniques to encode video, consisting of a base layer for base video quality and enhancement layers for improved quality.

Traditional Dynamic Adaptive Streaming over HTTP (DASH) with Advanced Video Coding (AVC) faces suboptimal quality adaptation. SVC addresses this challenge by enabling in-segment quality adjustments due to its layered structure, allowing for smoother quality degradation.

A detailed study of the SVC layered coding structure shows that base-layer data is essential for continuous playback, whereas enhancement-layer data, while beneficial, is not strictly required.

Our findings indicate that occasional drops in enhancement-layer data has minimal impact on user Quality of Experience (QoE).

Building on these insights, we propose an approach that integrates SVC with a partially reliable transport protocol to optimize video streaming.

By prioritizing base-layer data over reliable transport channels while opportunistically transmitting enhancement layers, our method ensures graceful quality adaptation in response to network fluctuations.

Acknowledgements

TODO: Complete acknowledgements

Content

TODO: We want to put an abbreviations section

Dedicated to WHATEVER.

Chapter 1

Introduction

1.1 Motivation

Discuss advantages of SVC over AVC. Discuss the potentional of SVC and PRT. We will need references here.

1.2 Research Questions

1.2.1 RQ1: Feasibility of Virtual Quality Levels in SVC

1.2.2 RQ2: Frame Importance using SVC Dependencies

1.3 Contributions

1.4 Outline

Chapter 2

Background

2.1 H.264/SVC Basics

Basic introduction of SVC features

2.2 Temporal Scalability

Hierarchical prediction structure for temporal scalability

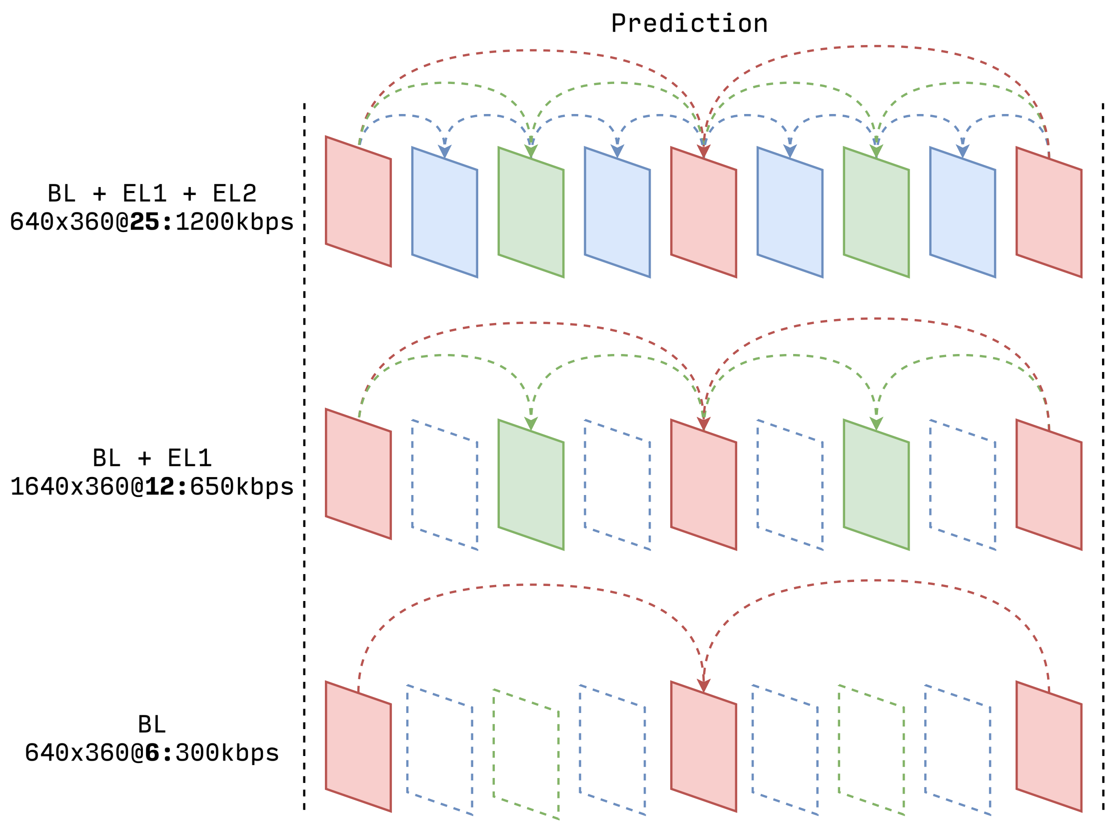


Figure 2.1: Temporal Scalability

2.3 Spatial Scalability

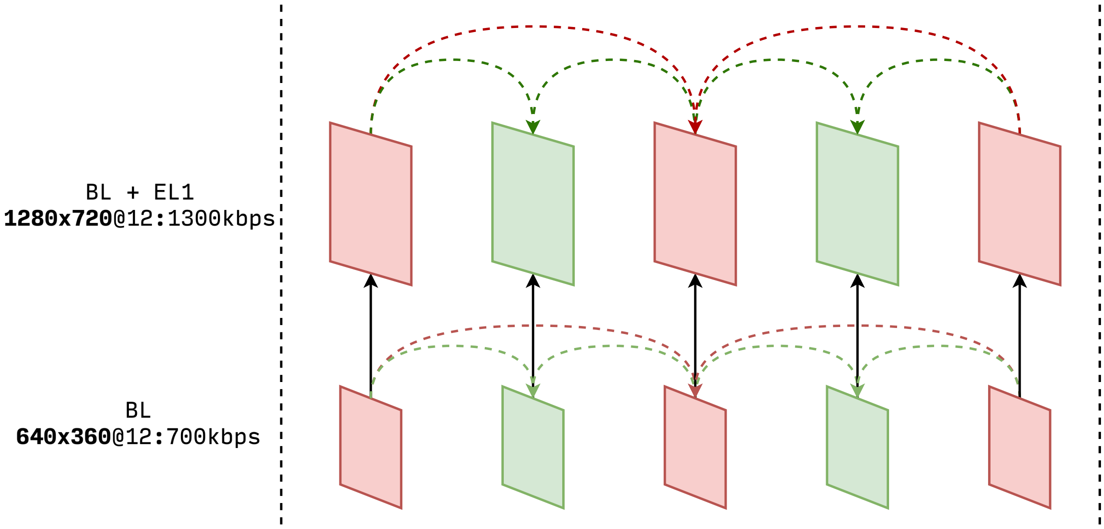


Figure 2.2: Spatial Scalability

2.4 Quality Scalability

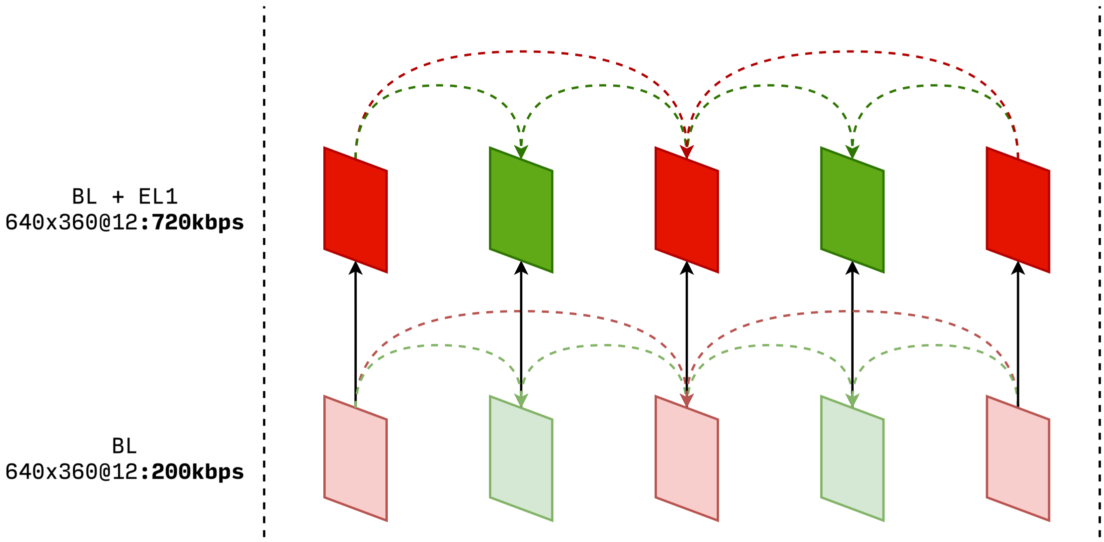


Figure 2.3: Quality Scalability

2.5 Combined Scalability

2.6 SVC Bitstream Structure

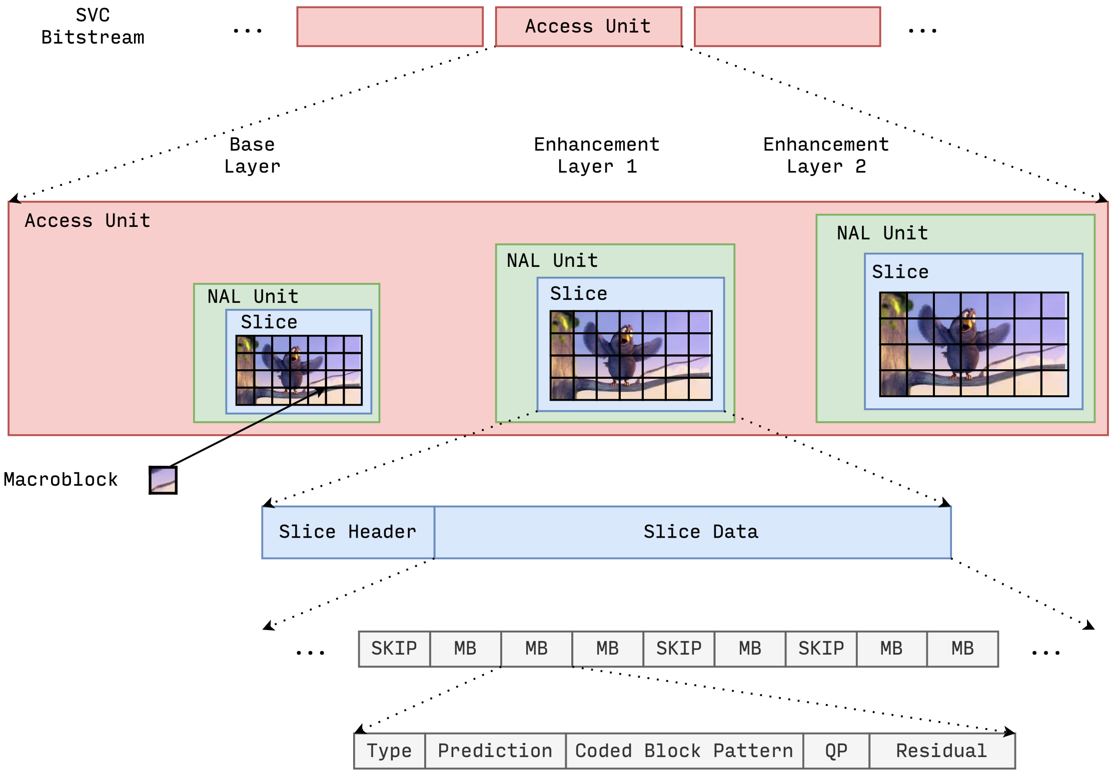


FIGURE 2.4: Bitstream Structure

2.7 Quality Metrics (SSIM, PSNR)

Chapter 3

Methodology

3.1 Inter-Layer Prediction in SVC

The purpose of inter-layer prediction in Scalable Video Coding (SVC) is to reduce the redundancy between the base layer and enhancement layers. This allows for higher compression efficiency without significantly increasing decoder complexity. These prediction tools are inspired by traditional single-layer prediction techniques in H.264/AVC but are extended to operate across layers.

In H.264/AVC, each macroblock is coded using either intra (texture) or inter (motion) prediction:

- **Texture prediction:** Uses spatial correlation by predicting the current MB from neighboring MBs within the same picture.
- **Motion prediction:** Uses temporal correlation by referencing previously decoded frames. Motion vectors and reference indices are used to point to predictive blocks in reference pictures.
- **Residual prediction:** After prediction (intra or inter), the difference/residual between the original and predicted block is transformed, quantized, and coded.

In SVC, these same principles are extended across layers through inter-layer prediction, where the enhancement layer reuses information from the co-located MB in the base layer:

- **Inter Layer Texture Prediction:** Analogous to intra prediction, but instead of spatial neighbors, the enhancement layer MB uses the reconstructed and upsampled co-located MB from the base layer. This enables the MB to be coded as *IntraBL*, saving bits by avoiding spatial prediction and residual transmission.

- **Inter Layer Motion Prediction:** Similar to AVC inter prediction, but the motion vectors, reference indices, and partitioning of the base layer MB are reused in the enhancement layer. For dyadic spatial scalability, motion vectors are upsampled by a factor of 2. Quarter-pel refinement can optionally be applied to improve precision.
- **Inter Layer Residual Prediction:** While AVC encodes the residual directly, SVC enhances this by allowing the residual of the base layer MB to be upsampled and subtracted from the enhancement layer residual before encoding. The encoder then transmits only the difference, reducing the residual bitrate.

Rate-Distortion Optimization (RDO) is used to decide whether to use these inter-layer modes on a per-macroblock basis, balancing bit cost against prediction accuracy.

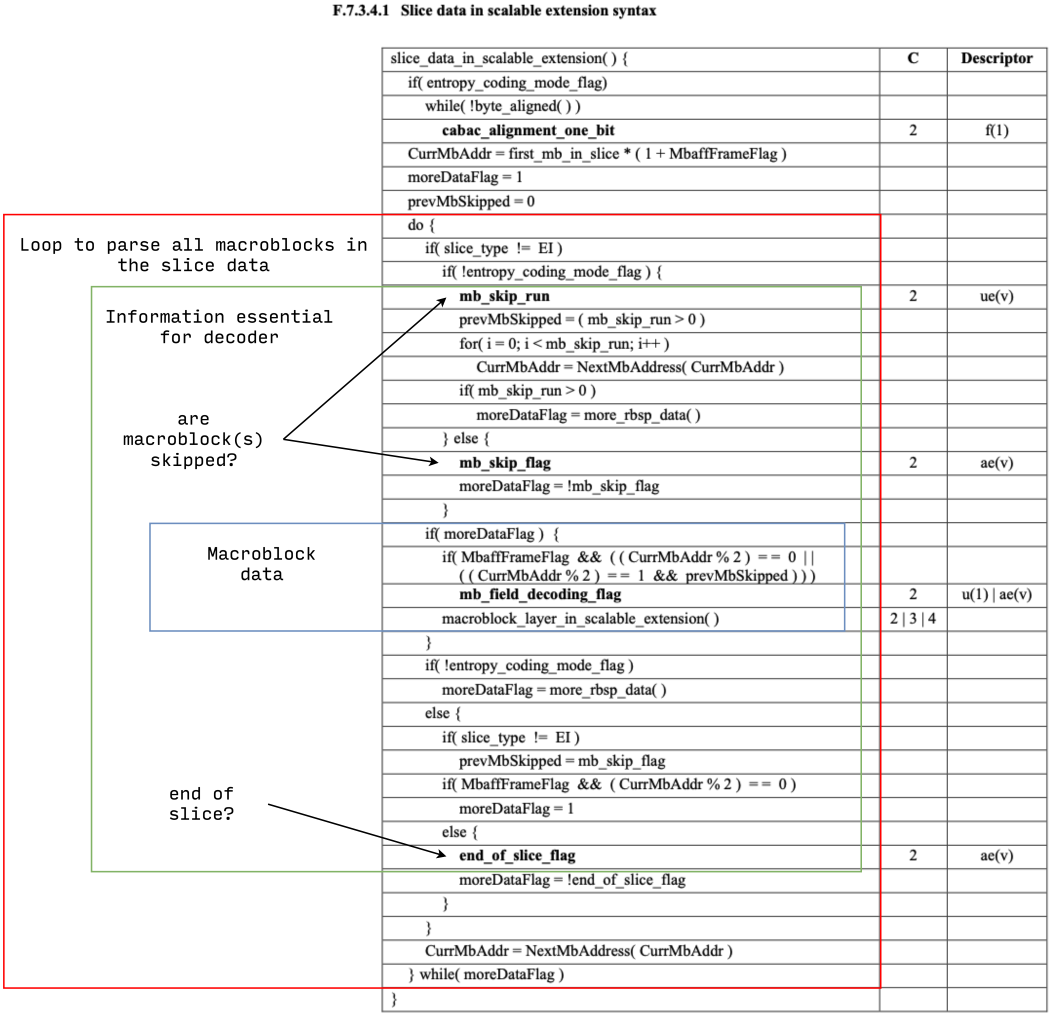
3.2 Macroblock Skips and Virtual Quality Levels

In this section, we investigate whether intermediate quality levels beyond the explicitly defined scalability layers can be created by partially omitting enhancement-layer data.

As introduced in Section 2.6, the SVC bitstream is composed of access units, each containing slices corresponding to different enhancement layers. Each slice includes a slice header and a slice data section, which holds a list of macroblocks. Macroblocks are the smallest coding units in the video and contain motion, prediction, and residual data used by the decoder to reconstruct the frame.

The slice data structure in the scalable extension is defined by the syntax shown in Figure 3.1. A key element of this syntax is the `mb_skip_flag`, which indicates whether a macroblock is skipped. Macroblocks can be skipped when their content can be predicted from reference frames with minimal impact on visual quality The primary purpose of macroblock skip mode in the H.264 is to reduce bitrate by avoiding the transmission of redundant information. When this flag is set, no motion vectors or residuals are transmitted for that macroblock and corresponding `macroblock_layer_in_scalable_extension()` syntax is omitted from the bitstream. Instead, the decoder reconstructs it using motion-compensated prediction from a reference frame. This mechanism is highly efficient, often requiring only a single bit to encode the skip decision, resulting in a reduced bitrate with minimal perceptual impact.

This skipping mechanism applies only to macroblocks in P and B-macroblocks, which are inter-coded and can be predicted using motion information and residuals from reference frames. In contrast, intra-coded I-macroblocks rely entirely on spatial prediction within the same frame and do not use motion vectors or residuals from other frames. Since there is no external reference available, skipping intra-coded macroblocks is not possible, and they must always be fully encoded.



F.7.3.4.1 Slice data in scalable extension syntax

slice_data_in_scalable_extension( ) {	C	Descriptor
if(entropy_coding_mode_flag)		
while(!byte_aligned( ))		
cabac_alignment_one_bit	2	f(1)
CurrMbAddr = first_mb_in_slice * (1 + MbaffFrameFlag)		
moreDataFlag = 1		
prevMbSkipped = 0		
do {		
if(slice_type != EI)		
if(!entropy_coding_mode_flag) {		
mb_skip_run	2	ue(v)
prevMbSkipped = (mb_skip_run > 0)		
for(i = 0; i < mb_skip_run; i++)		
CurrMbAddr = NextMbAddress(CurrMbAddr)		
if(mb_skip_run > 0)		
moreDataFlag = more_rbsp_data( )		
} else {		
mb_skip_flag	2	ae(v)
moreDataFlag = !mb_skip_flag		
}		
if(moreDataFlag) {		
if(MbaffFrameFlag && ((CurrMbAddr % 2) = = 0 || ((CurrMbAddr % 2) = = 1 && prevMbSkipped)))		
mb_field_decoding_flag	2	u(1) | ae(v)
macroblock_layer_in_scalable_extension( )	2 | 3 | 4	
}		
if(!entropy_coding_mode_flag)		
moreDataFlag = more_rbsp_data( )		
else {		
if(slice_type != EI)		
prevMbSkipped = mb_skip_flag		
if(MbaffFrameFlag && (CurrMbAddr % 2) = = 0)		
moreDataFlag = 1		
else {		
end_of_slice_flag	2	ae(v)
moreDataFlag = !end_of_slice_flag		
}		
}		
CurrMbAddr = NextMbAddress(CurrMbAddr)		
} while(moreDataFlag)		
}		

FIGURE 3.1: Slice data syntax in H.264/SVC

In our approach, we leverage this skip mechanism to omit macroblocks in the enhancement layers. For each macroblock we want to skip, we set the `mb_skip_flag` and remove the associated `macroblock_layer_in_scalable_extension()` syntax. This allows us to drop enhancement layer data in a controlled way while preserving the decodability of the bitstream.

By skipping macroblocks in the enhancement layers, we create modified versions of the original bitstream that has degraded visual quality. These degraded versions represent quality levels that are not explicitly provided by the original SVC bitstream. We refer to these intermediate representations as *virtual quality levels*. Each virtual level reflects a unique quality point created by partially omitting enhancement data, offering finer granularity between the standard quality steps defined by the encoder. This allows for smoother quality transitions and more flexible adaptation to available network resources than conventional SVC layer switching.

In the following sections, we evaluate these virtual quality levels using objective video quality metrics such as SSIM, PSNR, and VMAF, and assess their potential for improving streaming adaptability under fluctuating network conditions.

3.3 Motion and Residual Upsampling

Macroblock skips can produce unacceptable playback quality due to missing data. In order to prevent such effects, error concealment techniques are highly desirable.

Error concealment refers to the techniques used to recover missing or corrupted data, typically due to packet losses during transmission. SVC error concealment techniques rely on spatial, temporal, or inter-layer redundancy to estimate the lost information and maintain acceptable playback quality. While originally designed to address unintentional losses, such techniques are also effective in scenarios involving deliberate omission of data.

In our approach, we use the *Base Layer Skip (BLSkip)* error concealment method to reconstruct macroblocks that are skipped in the enhancement layer. For skipped macroblocks in the enhancement layer, BLSkip operates as follows:

1. If the co-located macroblock in the base layer is intra-coded, inter-layer texture prediction is used to generate the enhancement layer content.
2. If the co-located macroblock in the base layer is inter-coded, both inter-layer motion prediction and residual prediction are applied. In this case, motion compensation is performed in the enhancement layer using the upsampled motion vectors from the base layer, and the residual signal is predicted accordingly.

This enables reconstruction of the skipped macroblock while preserving visual quality.

Chapter 4

Evaluation

4.1 Experimental Setup

4.1.1 Test Videos and Encodings

We selected four publicly available test videos from the Xiph.org video dataset 1, varying in content and motion complexity. All videos are available in the raw YUV format (YUV420p, 1080p, 24 fps), therefore PSNR and SSIM values of the encoded videos can be calculated accordingly.

Title	Length	Type
blue_sky	217 frames	Movie
pedestrian_area	375 frames	Animation
rush_hour	500 frames	Animation
riverbed	250 frames	Animation

Table 4.1: Video Dataset Used for Evaluation

Each video was encoded into three SVC variants, with each variant using a different type of scalability, to independently study the impact of enhancement layer loss for each type: **Quality**, **Temporal**, and **Spatial**.

- `ONLY_QUALITY` variant uses one base layer and two quality enhancement layers. All layers are encoded at a fixed resolution of 360p. The base layer employs coarse quantization to provide a low-quality baseline, while the enhancement layers use SNR scalability to progressively improve visual quality.

- `ONLY_SPATIAL` variant uses spatial scalability, where each layer increases the resolution of the video. The base layer is encoded at 360p, followed by enhancement layers at 720p and 1080p.
- `ONLY_TEMPORAL` variant uses temporal scalability, where all layers are encoded at a fixed resolution of 360p, and each layer increases the frame rate of the video. The base layer is encoded at 6 fps, followed by enhancement layers at 12 fps and 25 fps.

TODO: we should add a bitrate column in the table

Configuration	Layers	Resolution	Frame Rate(fps)	Enhancement
	BL	360p	25	–
`ONLY_QUALITY`	EL1	360p	25	Quality
	EL2	360p	25	Quality
	BL	360p	25	–
`ONLY_SPATIAL`	EL1	720p	25	Spatial
	EL2	1080p	25	Spatial
	BL	360p	6	–
`ONLY_TEMPORAL`	EL1	360p	12	Temporal
	EL2	360p	25	Temporal

TABLE 4.2: Layer Structure of Test Variants

4.1.2 Evaluation Methodology

Our evaluation consists of four main stages: generating layered bitstreams, applying controlled degradation, decoding and assessing video quality, and aggregating the results.

TODO: do we need a diagram to show this methodology?

FIGURE 4.1: Evaluation pipeline overview

We begin by creating separate scalable video bitstreams, each representing a different enhancement configuration. The enhancement configuration is shown in Table 4.3. These configurations allow us to evaluate how the presence of additional enhancement layers affects video quality under loss.

Stream Id	Stream Configuration
`BL`	BL
`BL_EL1`	BL + EL1
`BL_EL1_EL2`	BL + EL1 + EL2

Table 4.3: Bitstreams extracted for evaluation

To simulate unreliable network transmission, we randomly skip macroblocks from the top-most enhancement layer in each configuration. We vary the amount of skipped macroblocks from 0-100%, increasing in steps of 10%.

Each degraded version of the bitstream is decoded using the JSVM Decoder v9.19. We then evaluate the quality of the reconstructed video using two commonly used objective metrics: Structural Similarity Index Measure (SSIM) and Peak Signal-to-Noise Ratio (PSNR). The original, unaltered video serves as the reference for comparison.

To account for the randomness of macroblock drops, each experiment is repeated multiple times per drop percentile. We then average the SSIM and PSNR scores across these runs to get stable quality estimates. Finally, we plot the average scores against the drop percentiles for each bitstream configuration

4.2 RQ1: Feasibility of Virtual Quality Levels in SVC

Discuss visual quality with dropped data

4.3 RQ2: Frame Importance using SVC Dependencies

Discuss visual quality with dropped data based on frame importance

4.4 Discussion of Findings

Chapter 5

Related Work

TODO: complete this section

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Table 5.1: Example of a table

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Chapter 6

Conclusion

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List of Figures

List of Tables

Bibliography

[1] N. G. De Bruijn. Lambda calculus notation with nameless dummies, a tool for automatic formula manipulation, with application to the church-rosser theorem. *INDAG. MATH*, 34:381–392, 1972.

Appendix A

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