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Master Thesis

Scalable Video for Peer-to-Peer Streaming

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Abstract

Pulsar is a peer-to-peer streaming software that allows the distribution of live and on-demand video files. *Pulsar* clients are typically comprised of a very diverse group of peers with varying local computing resources or network conditions. Thereby, scalable video coding provides an efficient solution to serve the different requirements as it allows to trade between bit rate and subjective quality.

This report concentrates on the topic of scalable video with respect to its application in peer-to-peer networks. In a first step various aspects of scalable video are discussed by an introduction on the existing Scalable Video Coding (SVC) standard of the Joint Video Team (JVT). Building on those explanations the implementation of scalable video in *Pulsar* is presented. Different parts of the software are discussed that had to be modified in order to allow *Pulsar* to cope with scalable video streams. The report is concluded by results from evaluation test runs regarding SVC alone as well as its application in *Pulsar*.

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Chapter 1

Introduction

Networks with an underlying peer-to-peer structure (e.g. *BitTorrent* [1], *Gnutella* [2], *eDonkey* [3], *Skype* [4]) have evolved over the past few years to a point where they form the basis for broadly used and established systems (e.g. *Kazaa* [5], *LimeWire* [6], *Morpheus* [7], *eMule* [8]). Thus, they are no longer solely of interest to the research community, but found their way to a wide range of mainstream applications. As peer-to-peer networks are gaining strength with a growing number of participants, their popularity will presumably not only sustain, but further rise.

The crucial feature of peer-to-peer networks that distinguishes them from conventional server-client architectures lies in their decentralized approach. Not a single server is responsible for distributing the content, but every interconnected peer acts as client and server at the same time. Therefore, a growing number of participants do not produce a heavier burden on the network, as it is the case with central servers. The opposite is true for peer-to-peer networks. Every new peer contributes more resources to the network, supporting the overall bandwidth and availability of content within the network.

The most widespread use of peer-to-peer networks can be found in the field of file-sharing systems ([5], [6], [7], [8]). They connect a vast amount of users for the purpose of sharing (i.e. interchanging) files. While the idea of peer-to-peer enjoys great popularity with file sharing systems the same cannot be confirmed when dealing with streaming content. Although the idea of peer-to-peer could equally well be expanded to streaming content, by now it is not yet a popular way of consuming audio or video sequences directly (without downloading it first) over the Internet.

One of the main reasons behind this slower adaption of the peer-to-peer concept in the field of streaming media lies in the inherent time-constrained nature of audio and video. In the case of only downloading a file, variations of bandwidth, only alters the point in time when the file is completely available. Whereas the same fluctuations can yield severe impacts on the perceptual quality of continuous audio or video streams. Thus, particular attention is required that the transfer of streaming content obeys certain restrictions regarding a constant bit rate over time.

The peer-to-peer streaming software *Pulsar* [9] takes care of exactly those constraints. It connects the peers within the network through a special routing protocol ([10], [11]) that strives to supply all members with a continuous stream of data. But managing and assuring a certain quality of service for all consumers within the network becomes a more challenging task as the requirements differ extensively between peers. They can vary among other points in regard to their local resources (e.g. computing power or screen size) and in available network bandwidth (e.g. up or down link bit rate). Such a variety of needs can turn out a challenging task for a network protocol to serve.

This is where scalable video comes into play. One possible solution to the challenge of a diverse group of peers could be to provide several different versions of the same video stream, each tailored to specific end user capacities - so called simulcast. Besides the increasing complexity in managing all those versions, simulcast also causes the peer-to-peer network to break apart. Since the various versions of the stream are conveyed completely independently from each other, peers requesting two different versions can no longer support each other. Hence, the group breaks apart into several smaller groups - each for one version of the media stream in question. This fact makes switching between different bit rates of a video stream a complex task. It not only requires the refresh of all packet buffers, it also induces the replacement of all neighbors. Therefore, adjusting the bit rate of a simulcasted video stream requires a complete reconstruction of the neighbor structure.

Scalable video strives to overcome this problem by avoiding the partition of peers according to their capabilities. With scalable video the different versions of a media file (in this case video) are consecutively build upon each other and therefore provide means for serving a variety of bit rates with a single stream. This increasing flexibility prevents the network from breaking apart and therefore simplifies the adjustment to the right bit rate.

This master thesis studies the characteristics of scalable video and what advantages it brings to applications in peer-to-peer environments. Furthermore a prototype implementation of a scalable video decoder in connection with Pulsar and comparing results from various test runs are presented. In addition the necessary modifications to the peer-to-peer protocol of Pulsar which enable the use of scalable video are discussed.

The remaining report is structured as follows: the following Chapter 2 provides an overview of already published work on the topic of scalable video in relationship with peer-to-peer networks. Chapter 3 introduces basic ideas of scalable video with specific focus on the Scalable Video Coding (SVC) extention of the H.264/AVC standard. In order to provide the necessary basis for further discussions, Chapter 4 gives a brief overview over the concepts behind the peer-to-peer streaming software *Pulsar*. Building on these explanations, Chapter 5 reviews those parts of *Pulsar* that were affected by the integration of scalable video. Chapters 6 and 7 finish the report by, respectively, presenting results from evaluation test runs and by giving a conclusion on the conducted work.

Chapter 2

Related Work

Papers related to the application of scalable video in peer-to-peer networks can broadly be categorized into three groups. The first one is comprised by publications out of the scalable video domain. Whereas the second group concentrates on the topic of peer-to-peer networks. Bringing both fields together forms a third group, which covers the deployment of scalable video standards in peer-to-peer networks.

2.1 Scalable Video

Probably the most important representative out of the first group would be the Scalable Video Coding (SVC) standard from the Joint Video Team (JVT). It originated from a proposal ([12], [13]) of the *Heinrich-Hertz-Institute*, which is part of the Fraunhofer Institute in Berlin. In its latest version the SVC standard is integrated as an amendment into the H.264/AVC specification [14]. A brief overview of the standard is provided in the subsequent paragraph of this report, while a more detailed outline is given by the paper of H. Schwarz, D. Marpe and T.Wiegand from the *Heinrich-Hertz-Institute* [15]. The reference software for the SVC standard (called Joint Scalable Video Model) can be found on the Internet [16]. Several related papers with different focuses on SVC can be found as well (Streaming: [17], Performance: [18], RTP: [19] and Mobile: [20]).

Another concept besides scalable video that is in some way related to it is Multi Description Coding [21]. MDC has similar intensions like SVC - altering the bit rate of a video - while using a completely different approach. The idea of MDC is to divide the coded video into several sub streams (i.e. descriptions). Each description alone can be decoded to a valid (but low quality) video stream. The final quality of the video improves with the number of available descriptions, until all descriptions decoded together finally form the original video stream.

The crucial difference of MDC to SVC lies in the prioritization of different parts of the video. While in SVC the layers bear a clear hierarchy (from the base layer to the last enhancement layer) the opposite is true for different MDC descriptions. Therefore, all parts within a MDC coded bit stream are equally important and contribute the same amount to the final quality. This property of MDC descriptions can be both: an advantage or disadvantage. Beneficial is the fact that two distinct descriptions never depend on each other. That means no matter which descriptions are available; they can always be assembled to form a valid video stream. The same is not possible with SVC layers, if one layer underneath is missing. On the other hand SVC utilized the fact that not all parts of a video are equally important to the final quality. Thus, it is possible to convey the essential parts in the base layer with enhancement layers only adding details to the final video. Furthermore, data portioning of MDC demands a substantial amount of coding overhead and increases the complexity of the decoder. That is why MDC is not yet considered by any of the traditional video coding standards.

2.2 Peer-to-Peer Networks

In the field of peer-to-peer networks the variety of scientific publications is even wider. Most peer-to-peer streaming networks of today use a neighbor selecting strategy that can be described as either tree-based or unstructured. Hence, first those two principal groups of networks and their prominent representatives are introduced. Followed by projects that - like Pulsar - apply Distributed Hash Tables (DHT) as a combination of those groups. Comprehensive overview papers discussing various types of peer-to-peer architectures are given by [22], [23] and [24].

Tree Based Overlays

Protocols based on a tree structure connect all peers via a rigid overlay. Each peer is obligated to forward incoming data packets to all of its children peers. Since the depth of such a tree stays rather small (logarithmic to the number of peers), information can be transmitted rapidly to all members of the network. Generally, transmission of data packets to other peers without having them explicitly requesting those packets is called a *push* operation.

Two main disadvantages hinder the application of basic tree based protocols: on the one hand maintenance overhead is large. Since the construction of a tree can be a complex and time consuming task, they form rather static structures that react inflexible if peers are constantly joining and leaving the network (called churn). The second drawback of trees is also related to their rigid nature: in their basic form each peer in the tree is only connected to one single parent peer. This not only puts a heavy upload burden on the parent node, it also makes the child node directly depended from the parent's capacities. Hence, all peers following further down in the tree as well suffer from a weak predecessor peer. Besides, peers functioning as leafs of the tree have no children and can therefore receive packets without contributing to other peers.

Narada [25], *Overcast* [26], *PeerCast* [27] or *FreeCast* [28] can be considered typical examples of the first group, the tree based peer-to-peer streaming networks. To overcome the problems imposed by a single tree structure, *CoopNet* [29] for example relies on multiple trees. In addition *CoopNet* provides a certain degree of video scalability and error resilience by coding the data in multiple descriptions (see section 2.3 on Multiple Description Coding). The same approach with MDC is also followed by the system called *Split Stream* [30]. The overlay of *CoolStreaming* [31] does use a structured overlay, but it resembles more a mesh [32] than a conventional tree.

Unstructured Overlays

Due to the mentioned disadvantages of tree based peer-to-peer networks, some systems avoid a rigid structure between the peers. Instead, each peer keeps just a list of its direct neighbors while there exists no global overlay on top of all peers. As a result peers are only aware of their direct neighbors. This leads to an improved flexibility in case of churn and avoids the time consuming task of setting up a tree structure. Moreover, peers joining or leave the network only cause very local modifications of the network.

Like tree-based overlays, also unstructured networks suffer from two downsides - both related to a missing global structure for coordinating the distribution of data packets. First, in contrast to *pushing*, peers in an unstructured overlay must explicitly request needed packets (called *pulling*). Such notify-and-request communication between two peers leads to an increased overhead and delays the delivery of packets. Second, due to the lack of a global overlay special attention is needed that the network stays connected as a whole. For example if peers strive to connect to neighbors that are physically closely located, a worldwide network can very easily break apart into local sub-groups. Nevertheless, unstructured overlays are in most cases favored over tree based ones, due to their better robustness against churn.

Two examples that follow the approach of an unstructured neighbor selection strategy are: *Chainsaw* [33] and *GridMedia* [34]. They differ primarily in the number of neighbor nodes that each peer has to keep. Also file sharing protocols like *BitTorrent* [1], *Gnutella* [2] and *Napster* [35] use similar concepts.

Distributed Hash Tables

Due to the mentioned disadvantages of tree-based and unstructured peer-to-peer networks, Pulsar relies a combination of both concepts (see Section 4). The employed prefix routing algorithm is comprehensively explained in [11]. The idea of prefix routing itself is based on the concept of Distributed Hash Tables (DHT). DHTs originated from the routing algorithm of *Plaxton* [36], which was originally devised for managing of web queries. For an introduction to DHT or the latest developments in this field the reader is referred to [37] and [38] respectively. The first four systems that started to use DHT about the same time were: *CAN* [39], *Chord* [40], *Pastry* [41], and *Tapestry* [42]. Especially the last two rely on routing algorithms simliar to the one used in Pulsar.

2.3 Scalable Video and Peer-to-Peer

Although both fields - scalable video as well as peer-to-peer networks - have attracted much attention from the research community, the amount of scientific papers focusing on their interaction is rather small. A very recent publication [43] employs SVC to guarantee smooth delivery of video content among the peers within the network. Their performance tests were carried out with a quality scalable video stream delivered over a *Gnutella* like (i.e. unstructured) peer-to-peer network. The evaluation indeed shows an improved video throughput rate to the peers (measured in kBits/sec) and an enhanced quality of the received video (measured in Peak Signal To Noise Ratio - PSNR). Still, it should be pointed out, that like with *Gnutella* the topology among the peers is built up arbitrarily (i.e. without a structured overlay).

The system described in [44] as well uses SVC in a peer-to-peer environment. Their theoretical analysis concentrates on quantifying the advantage of SVC with respect to single layer video coding. The quality gains are measured in PSNR and are calculated depended on the bandwidth capacities of the peers. Especially in networks with a heterogeneous bandwidth distribution the strength of SVC becomes obvious. Their practical tests were conducted on the real time streaming protocol called *Stanford Peer-to-Peer Multicast* (SPPM) [45]. The results prove that especially in cases of a congested network SVC outperforms single layer coding. That is due to fact that prioritization of the layers allows to play at least the most important layers, even if the video is not completely received. Whereas, if bandwidth is not the bottle neck, single layer coding benefits from its better coding efficiency.

Besides SVC, some interesting papers about MDC have been published in the context of peer-to-peer. An older but still comprehensive overview of MDC video streaming in peer-to-peer networks is given by [46]. The paper also compares MDC to the scalability functionality of MPEG-2 and MPEG-4 - the predecessor of the SVC standard today. The approach presented in [47] employs a method called flexible Multi Descriptions Coding (F-MDC) which is based on wavelet compression. F-MDC simplifies the partitioning of an encoded video stream into a specific number of descriptions. This video codec is subsequently deployed in a receiver centric (many to one) peer-to-peer network. A paper concentrating more on the incentives aspect of MDC can be found in [48]. It is based on the principal that peers contributing more to other peers also get a larger number of different descriptions and consequently enjoy a better video quality.

2.4 Commercial Peer-to-Peer Video Streaming

Currently many peer-to-peer clients are available on the web that offer free video streaming (but without the functionality for scalable video). Among the most prominent ones are systems like *Zattoo* [49], *Tribler* [50] or *Joost* [51]. All of them rely on similar concepts: offering professional TV shows alongside private content and making money through advertisement. The advantage for TV stations is that they can make their program worldwide available, while shifting the costs for broadcasting to the individual users. Also in Asia *P2PTV* applications like *TVUPlayer* [52], *PPLive* [53] or *Cool-Streaming* [31] are becoming more and more popular.

Chapter 3

Scalable Video

The term "scalable" in the context of video stands for the general concept of coding an image sequence in a progressive (i.e. scalable) manner. Meaning, the internal structure of the coded video allows for a trade-off between bit rate and subjective quality. The additional flexibility is provided if parts of the video bit stream can be discarded with the result still representing a valid video sequence. This requires a layered structure within the coded video that distinguishes basic information from parts that represent only details. In this way, a video can be adjusted in a fast and easy way to changing network conditions or the specific capabilities of the end users. With this concept in mind, scalable video can also be compared to progressive JPEG [54] in the still image domain. Progressive JPEG offers the possibility to transmit the low frequency parts of the image first, giving a preliminary impression of what the final image would look like. All following higher frequency information builds upon the first version and accumulates finer details.

3.1 Benefits of Scalable Video

Previous to any further discussion about relevant aspects of encoding a video in a scalable manner, the motivation behind this idea should be outlined. Broadly speaking, scalable in comparison to non-scalable videos provides the following advantages.

- In case of simulcasting, several different versions of the same video must be available in order to serve diverse user requirements. Obviously those different versions bear a high degree of redundancy. Although encoded for different bit rates, they all represent the same content. Scalable video strives to reduce this redundancy and can therefore produce a video stream that requires significantly less storage space than the sum over all versions of a simulcast video stream.

- In addition, scalable video streams can be encoded in a way to offer more than a limited number of different bit rate points (see Section 3.2.3 on Quality Scalability). With this fine graduation the choice among bit rates is expanded to a whole range of possible values.

- The management of different bit rate versions for the same video is avoided. With scalable video just one bit stream can serve a diversity of client needs. As a consequence the adjustment of the bit rate is simplified. It no longer involves switching between two separate bit streams, but can be carried out within the same video stream. This convenience improves the flexibility of the video stream and increases the resilience against variations or failures of the transmission link.

- In representing the encoded video in a layered structure, scalable video assigns different importance to each layer. The base layer of a scalable video stream comprises information that is fundamental for the playback of the video. Thus, it represents the most important parts of the video stream. As the order of the enhancement layers on top increases their importance decreases.

The advantage of this layered structure is that specific parts of the encoded video stream can be prioritized. In a network environment with limited band width capacity this prioritization enables to prefer those data packets that are essential for the playback of the video. Hence, in cases were not enough band width is available to receive the whole video, scalable video offers at least a low quality version of that video.

- Especially for peer-to-peer networks scalable video offers another advantage that is related to the previous one. Generally, all peers of a network do not form a homogenous group, but differ in their bandwidth or computing capacities. Thus, in case of simulcast, they would demand different bit rates of the video and consequently also request different streams. This leads to the problem that the overlay of the peer-to-peer network is breaking apart into smaller sub-groups. Each sub-group shares only one version (i.e. bit rate) of the video stream.

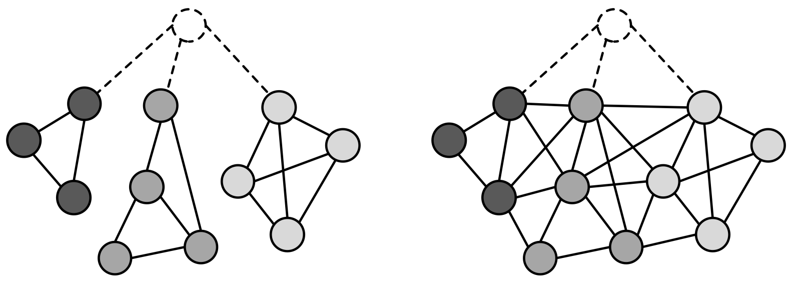

(a) Simulcast (b) Scalable Video

Figure 3.1: Break-up of Peer-to-Peer Network

In Figure 3.1 the source offers three different bit rates for one video. The peers are grouped according to the requested bit rate (indicated by shades of gray). In case of simulcast (3.1(a)) the bit rates are represented by three different streams. Therefore, peers with different bit rates cannot exchange data packets and form separate sub-groups. This

This separation of peers becomes in particular problematic in cases of STARK band width fluctuations. If the available band width changes, peers may react to the new situation by requesting a different bit rate of the current video stream. In case of a simulcasted video streams, the only way to do so is to request a different stream. Since the old and the new stream are independent from each other, switching between them requires leaving one group of peers and joining another one. Therefore, the whole neighbor structure has to be rebuilt.

Scalable video overcomes this complex switching task by offering one stream that can serve a variety of bit rates (Figure 3.1(b)). Hence, all peers stay within the same group, regardless of the requested bit rate. This simplifies switching between bit rates and consequently improves the robustness of the system.

In addition, the robustness of the peer-to-peer network further benefits from another advantage of wide group of peers. The performance of a peer-to-peer network relies on a profound number of peers that are willing to share their upload capacity. If more peers offer the same video stream the robustness of the whole network is improved, because a failure of one peer can very easily be compensated by other peers.

However, it is important to notice that the increased flexibility of scalable video also produces a certain amount of data overhead that reduces the coding efficiency of the video stream. This overhead is studied more closely in the evaluation part of

Section 6.1.1. In addition, the complexity of scalable video encoders and decoders is considerable higher in comparison to their non-scalable counterparts.

After this brief analysis of the arguments for employing scalable video in peer-to-peer networks, the remainder of this chapter concentrates on specific aspect of scalable video.

3.2 Scalable Video Coding Extension

Scalable video has been an active research area in the video coding community for more than a decade (and still continues to do so). The latest standard out of this effort derives from the Joint Video Team (JVT) of the ITU-T Video Coding Group (VCEG) and the ISO/IEC Moving Picture Expert Group (MPEG). In 2007 they published the standard called Scalable Video Coding (SVC)[14], which as an extension forms part of the H.264/AVC standard [55]. Since the SVC standard considers most of the aspects of scalable video and furthermore plays an important role within the scalable video prototype of Pulsar, the following paragraphs give a short overview over the basic concepts found in this standard.

As an extension SVC depends upon the main design decisions found in the regular H.264/AVC video coding standard. Therefore it reuses concepts like hybrid video coding (i.e. inter-frame prediction in combination with intra-frame prediction), transform coding or the underlying macro block structure. A detailed description of those principals can be found in [55]. The core design concept of SVC which distinguishes it from its parent standard is the layered structure of the coded video. Specific parts of the bit stream are grouped according to their importance on the final quality of the video. Within the SVC standard three different possibilities are described to divide the video into several layers. In accordance with the SVC reference paper [15] this report uses the term scalability dimensions for those three criteria. They are namely: Temporal Scalability, Spatial Scalability and Quality Scalability and will be described more closely in the next few paragraphs.

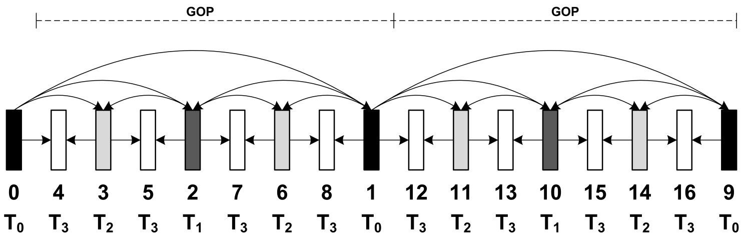
3.2.1 Temporal Scalability

Scaling a video via its temporal resolution basically means altering its frame rate. Simply discarding random frames from the video sequence is not feasible, because other frames may depend upon them for motion compensation. So, in order to provide the choice between several frame rates, the frames must be encoded in a certain manner - also called hierarchical prediction structure ([56], [57]). A sketch of this prediction order is found in Figure 3.2. The numbers underneath the frames indicate their ordering within the coded bit stream.

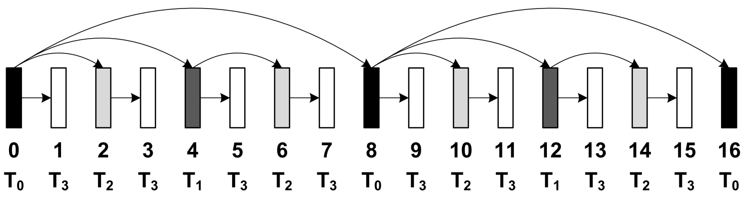
Figure 3.2(a) shows consecutive frames and their dependencies from motion prediction. As can be seen, the reference frames are not arbitrarily chosen, but in a way that a hierarchy is arranged between all frames. In the graphic those levels of hierarchy are marked in different shades of gray and are denoted by T_k with k being the identifier of one temporal layer. Frames between two successive frames from the lowest frame rate (i.e. highest hierarchy T_0) together with the subsequent T_0-frame are referred to as a *Group of Pictures* (GOP). The crucial thing about this prediction structure is that frames of one temporal layer k only depend on frames from the same or lower layers. Therefore, layers with an identifier larger than k can be discarded from the bit stream without influencing frames further up the prediction hierarchy.

The following two figures (3.2(b) and 3.2(c)) show further examples of hierarchical prediction. Example 3.2(b) depicts a possible solution, where motion prediction is still conducted in a hierarchical fashion, while avoiding a structural delay in the decoding process of the sequence. Also noticeable by the lack of backward prediction (i.e. reference images from the future) and the steadily increasing encoding order of the frames. However, this solution comes at the price of lower coding efficiency, as shown in the evaluation part (Section 6) further down. In Figure 3.2(c) the frames are arranged in a non-dyadic way. Thus, the frame rate does not increase by a factor of 2 from one layer to the next.

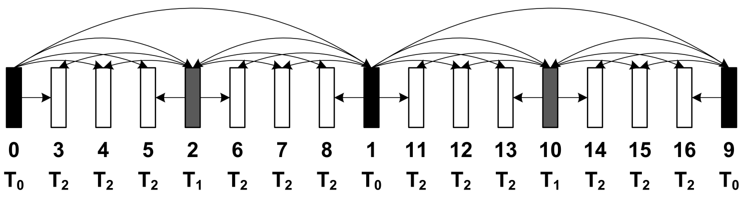
Basically the concept of different temporal resolutions can just as well be achieved through pure H.264/AVC. The advanced flexibility of H.264/AVC for choosing and controlling reference frames [55] already enables the use of hierarchical motion prediction. SVC just adds methods of signaling and labeling the temporal layers in order to subsequently extract them without difficulties.


GOP
GOP
0 4 3 5 2 7 6 8 1 12 11 13 10 15 14 16 9
T_0 T_3 T_2 T_3 T_1 T_3 T_2 T_3 T_0 T_3 T_2 T_3 T_1 T_3 T_2 T_3 T_0

(a) Four Temporal Layers


0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
T_0 T_3 T_2 T_3 T_1 T_3 T_2 T_3 T_0 T_3 T_2 T_3 T_1 T_3 T_2 T_3 T_0

(b) Non-Delay Motion Predication


0 3 4 5 2 6 7 8 1 11 12 13 10 14 15 16 9
T_0 T_2 T_2 T_2 T_1 T_2 T_2 T_2 T_0 T_2 T_2 T_2 T_1 T_2 T_2 T_2 T_0

(c) Non-Dyadic Temporal Layers

Figure 3.2: Hierachical Motion Predication

3.2.2 Spatial Scalability

While the previous paragraph dealt with temporal resolution, spatial scalability corresponds to different image resolutions. Similar to image pyramids, every new layer within a spatial scalable bit stream improves the final image resolution [58]. Figure 3.3 demonstrates this idea with one base layer S_0 and two enhancement layers (S_1 and S_2). In this case not only the size, but also the number of pictures in each layer differs, which leads to a combination of spatial (S_k) and temporal resolution (T_k).

The main advantage of SVC over simulcasting each layer separately, is marked in this graphic by the vertical arrows connecting two layers. They illustrate the concept called inter-layer prediction. This prediction method strives to reuse as much information as possible from one layer to the next. This avoids redundancy between the layers and subsequently improves coding efficiency. Similar to motion prediction within one layer, in the case of inter-layer prediction first the final image is predicted from the corresponding picture in the reference layer and only the differences to the actual image (also called residuals) are finally encoded.

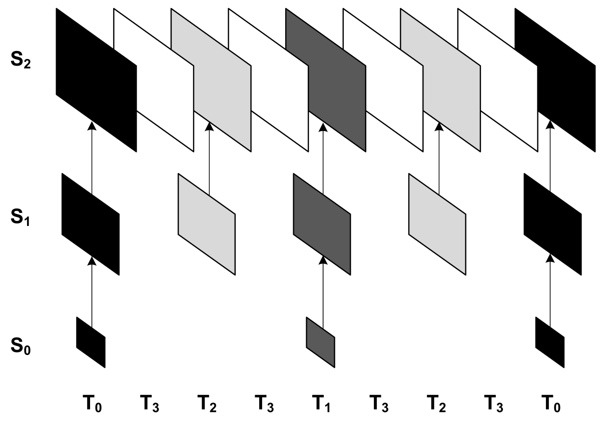


Figure 3.3: Three Spatial Layers

The most efficient way to perform inter-layer prediction would be to depend on the completely reconstructed or decoded picture from the layer underneath. This straight forward method, however, would significantly increase the complexity of the decoder, due to the requirement of fully decoding all underlying layers. In order to keep the decoding process simple and avoid multiple decoding loops, the SVC standard provides inter-layer prediction methods that permit so called single-loop motion compensation. With single-loop compensation, motion estimation at the encoder is conducted in all layers, while the expensive process of motion compensation at the decoder is only required in the target layer. This is guaranteed if information from the lower layers can be used in the target layer without decoding. Though single loop motion compensation slightly decreases coding efficiency, it significantly simplifies the structure of the decoder [59], [60]. Hence, the following three inter-layer prediction techniques recycle information from low level layers without entirely decoding them.

Inter-Layer Motion Prediction

When thinking of conventional motion prediction from H.264/AVC and similar standards, there are two main components that are encoded for each B or P (i.e. motion predicted) macro block: the motion vector and the corresponding residual information. In accordance with this, the first two inter-layer prediction methods concentrate on those two parts. Since motion vectors are not likely to change too much from one layer to the next (except for the scaling factor), they offer a good opportunity to reduce redundancy. Inter-layer motion prediction makes use of this fact by copying motion vectors and additional information (macro block partition and reference picture indices) to layers that are further up the hierarchy. After rescaling, the copied motion information either functions as prediction for the actual motion vectors or is directly used for motion compensation.

Inter-Layer Residual Prediction

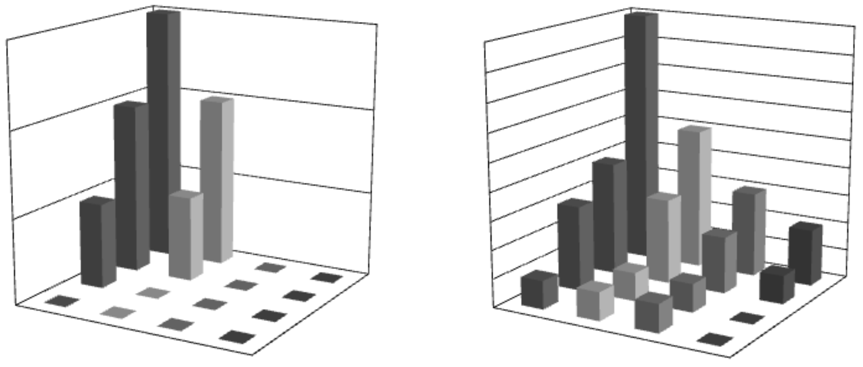
In addition to motion vectors SVC also provides means for reusing residual information. Therefore only the difference signal to the up scaled residual from the lower layer needs to be encoded. Although inter-layer motion and residual prediction together exploit most of the information present in the lower layer, it is still not necessary to decode the reference layer. Hence, the concept of single loop motion compensation is still satisfied.

Inter-Layer Intra Prediction

This prediction technique goes one step further. Inter-layer intra prediction applies a reconstructed version of the corresponding picture in the reference layer as prediction. This does require the decoding of the lower layer and is therefore only allowed for intra predicted macro blocks. Those kinds of macro blocks are predicted without motion references to other frames, which guarantees that they can be decoded without running a separate motion compensation loop.

3.2.3 Quality Scalability

During encoding the textural information for each macro block is transformed to the frequency domain. For efficiency reasons those transform coefficients are quantized before they are finally encoded. In this way, the coefficients are mapped to a limited number of quantization levels. What quality scalability (also called fidelity or signal-to-noise scalability) basically does is influencing the number of these quantization levels. Thereby, quality scalability achieves refinement in image quality through gradual downsizing of the quantization steps. Smaller quantization steps yield more quantization levels and consequently a finer graduation of the transform coefficients (Figure 3.4). This leads finally to an improved image quality with a higher degree of details.



(a) Four Quantization Levels (b) Ten Quantization Levels

Figure 3.4: Quantization of Transform Coefficients

Looking more closely, this method can be considered a special case of spatial scalability. If the image resolution does not change from one spatial layer to the next, refinement is also solely achieved through smaller quantization steps. This approach of dividing the video into several quality layers is called Coarse Grain Scalability (CGS). Therefore, CGS layers can be considered special cases of spatial layers. One disadvantage of CGS is inherent to spatial scalable layers. Motion estimation is conducted in each spatial layer separately (see Figure 3.5(a)), which makes switching between two spatial layers only possible at well defined points within the video stream (i.e. at I-frames). Another drawback of CGS is already revealed by its name: the choice among different bit rates is limited to the number of CGS-layers. Fine graduation in between two CGS layers is not possible.

Hence, the SVC draft also considers other means for quality scalability besides CGS. All those alternatives take place within one spatial layer and therefore all quality layers rely on the same motion compensation loop. In Figures 3.5(b), 3.5(c) and 3.5(d) this fact is pointed out by the lack of gaps between the quality layers. Because all quality layers within the same spatial layer are based on the same motion prediction loop, the crucial question then is, which quality level of the reference picture is used for motion compensation?

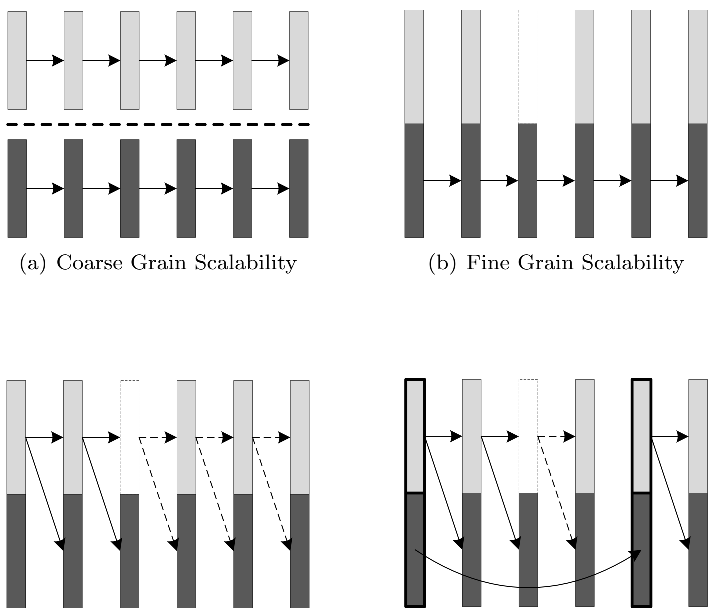

(a) Coarse Grain Scalability (b) Fine Grain Scalability (c) Drift (d) Medium Grain

Figure 3.5: Different Quality Scalability Methods

One possible solution called Fine Grain Scalability (FGS) is exemplified in Figure 3.5(b). FGS always performs motion compensation on the lowest quality level of the reference picture. The advantage of FGS is that motion estimation at the encoder and motion compensation at the decoder always use the same quality level of the reference picture. This is guaranteed by the fact that at least the base layer is always available at the receiver. If motion prediction is only conducted in the lowest fine grain quality layer, a loss of refinement packets (e.g. in the third frame of Figure 3.5(b)) does not influence the motion compensation loop. This fact allows to scale the bit rate of a video stream on a packet based level, by simply discarding specific packets out of the enhancement layer. Therefore, FGS ensures that the encoder and decoder are synchronized at all times. However, the cost of this solution arises in a reduced coding efficiency, because the more accurate information from the quality enhancement layers cannot be exploited for motion prediction.

The obvious way to reuse as much information from the reference picture as possible would be to perform motion prediction in the highest of the quality layers. This technique together with its major disadvantage can be seen in Figure 3.5(c). While the reference picture is used in a very efficient way, the video stream becomes susceptible for a phenomenon called drift. Drift describes a situation when the encoder and decoder motion predictions loops are no longer working on the same reference images (i.e. are running out of synch). If some packets of the enhancement layer have been discarded during transmission, the decoder cannot detect this situation and applies a lower quality reference picture for motion compensation as the encoder did. In Figure 3.5(c) motion estimation at the encoder is conducted in the enhancement layer, while for the third frame only the base layer arrives at the decoder. Hence, the reference picture of the fourth frame is incomplete, which can lead to visual artifacts in the decoded video sequence. Furthermore, the effects due to drift accumulate over time, leading to a severe loss in video quality over time.

Therefore, SVC introduces a tradeoff between CGS and FGS, in order to fine tune the video quality, while keeping the drift at an acceptable level. The idea of the so called Medium Grain Scalability (MGS) concept is depicted in Figure 3.5(d). The improvement in respect to the already mentioned FGS lies in the flexibility to choose, which quality layer is employed for motion prediction. In this way motion prediction can still be conducted in the enhancement layer, but with periodic updates in the base layer. Those periodic updates happen at so called *key pictures* and synchronize the decoder motion compensation loop with the one from the encoder. In Figure 3.5(d) at every fourth frame is a *key picture* where motion prediction is synchronised by updates in the base layer. Thus, MGS guarantees that the effects of drift are not getting too acute.

3.2.4 Combination of the Scalability Dimensions

All of the three introduced scalability dimensions can be combined with each other. The schematic structure of such a bit stream can be seen in Figure 3.6. The most important classification refers to the spatial layers of the SVC video stream. Within one spatial layer there can reside one or more temporal and quality layers.

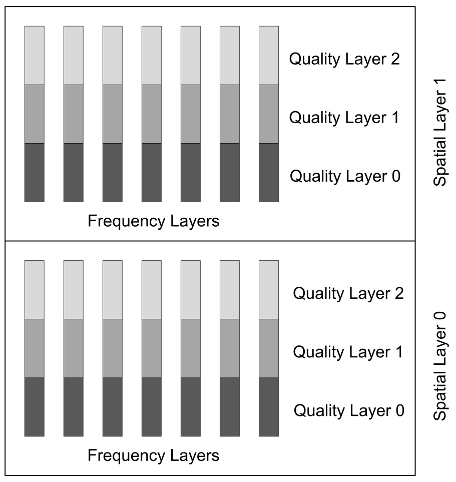


Figure 3.6: Combined Scalability Dimensions

Chapter 4

Pulsar

In order to keep the report self-contained this chapter is dedicated to the Push-to-Pull protocol that forms the foundation of the Pulsar streaming software. It outlines the principal concepts and provides the basis for a discussion about aspects relevant to the integration of scalable video (see Chapter 5). For those characteristics of the protocol that are not covered by this brief overview the corresponding papers [10] and [11] are recommended.

As already stated in the section about related work in Chapter 2, peer-to-peer networks can broadly be classified according how individual peers select their neighbors. Those neighbor selecting strategies subsequently induce the structural overlay of the network. Due to the mentioned problems of the two main groups of overlay structures, tree-based and unstructured overlays, Pulsar strives to combine both concepts. This combination is achieved by conducting a two phase approach for distributing data packets. In this way strengths of one concept can tackle weaknesses of the second one. Hence, the next two paragraphs are dedicated to the initial pushing and the subsequent pulling phase.

4.1 Pushing

The intention of the first pushing phase is the rapid distribution of data packets to a majority of peers. Therefore, the efficiency of tree-based overlays is exploited. Concerning the structure of the tree, ideas from Distributed Hash Tables (DHT) are borrowed. As explained in [37] DHTs are special hash tables with their values (i.e. buckets) distributed among several locations (i.e. peers). More precisely, a DHT provides means for deciding where to store and subsequently retrieve data in a distributed environment. Therefore, for each value to be stored, a unique key is generated (usually a bit string), which determines the final node for depositing the value. In peer-to-peer networks for example those keys are used for routing through the overlay to the final destination peer.

Pulsar itself does not utilize DHTs for storing data. It just borrows the idea of routing for pushing packets along a tree-like overlay. The difference in Pulsar is that packets should not be routed to a single destination (as for storing), but to as many peers as possible. Therefore, each peer hands incoming packets to all its children instead of just one.

In order to avoid a rigid tree structure, each peer should have a certain degree of freedom for choosing children nodes. This is achieved by the so called prefix routing technique (figure 4.1). The term "prefix" refers to the first digits of the peer identifier. When choosing children nodes to forward a packet, parent nodes can decide between several peers. The choice between children is restricted to peers that satisfy the following three constraints:

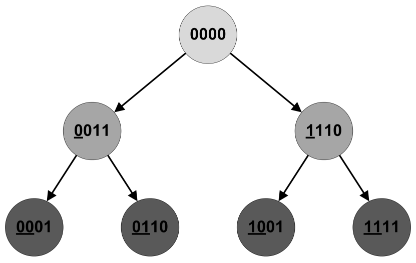


Figure 4.1: Prefix Routing (Prefixes are underlined)

- The child node is new to the tree (i.e. no loop).
- The child prefix equals the parent prefix.
- All child identifiers must differ in the first digit after the prefix.

Figure 4.1 illustrates the concept of prefix routing on a simple example. The bit strings in the middle of every peer indicate the identifiers with the prefix comprising the first underlined digits. Each peer can now choose its child nodes under the before mentioned constraints. The source (`0000`) for example selects two child nodes that start with `0XXX` and `1XXX` respectively (with `X` being eather `0` or `1`). At every hop the prefix is expanded to comprise one more digit of the identifier. Therefore, the peer `0011` is restricted to choose child nodes with the follwing pattern: `00XX` and `01XX`. This restriction in connection with the first constraint further limits the freedom of choosing child nodes at each hop. At the same time the second constraint ensures an equal distribution of packets within the network.

While profiting from the efficiency of a tree based structure, prefix routing still avoids a rigid overlay. Therefore, the flexibility of choosing a neighbor can for example be used to favor closer peers or to react to churn.

4.2 Pulling

Distributing packets by solely relying on prefix-based pushing does not guarantee that all peers within the network are actually reached. That is why the push phase is followed by subsequent pull operations. In this second phase peers that were not reached during the pushing phase request missing packets in an unstructured manner. Meaning that peers notify their neighbors about received packets and they in turn can request these available packets. The latency of pull operations is diminished in this case, because the prior push step already brought the data packet close to almost all peers.

In addition, the pulling phase offers the possibility to incorporate incentive mechanisms for motivating peers to share their upload capacity and provide other peers with received packets. Incentive mechanisms are essential for all peer-to-peer networks, since they rely on the upload contribution from all peers and would suffer from "selfish" peers that consume packets without further forwarding them. Basically, pull based packet distribution simplifies the task of controlling fair collaboration from all peers, because a bidirectional packet exchange takes place. Thereby Pulsar employs an incentive mechanism similar to the *tit-for-tat*-concept of [61]. With the *tit-for-tat*-concept peers only offer packets, if they receive other packets in return. Since the only way to get packets is to exchange them with other packets, selfish peers can be avoided to some degree.

By combining push and pull based packet distribution Pulsar is able to rapidly reach all peers while still staying robust against churn. For a comprehensive assessment of this property the reader is referred to the evaluation part of [10]. After this general overview of the Pulsar protocol we want to take a closer look in the next chapter on those aspects that are important for integrating scalable video.

Chapter 5

SVC and Pulsar

The last two sections concentrated on scalable video and Pulsar separately. In the following paragraphs both fields are brought together by discussing the actual modifications that were necessary in order to integrate scalable video streams into Pulsar. All necessary modifications are dealing eather with Pulsar or the JSVM reference software. Thus, the follwing two paragraphs concentrate on those topics respectively.

Although this chapter almost exclusively talks about scalability in the field of video, all concepts were designed to be as generic as possible. This offers the possibility to expand the idea of scalability to other media content types such as audio. Furthermore, a different scalable video format could be used as well. Only in places where SVC is explicitly mentioned the discussion is restricted to the scalable video coding standard of the same name.

5.1 Modifications concerning Pulsar

The following modifications on the Pulsar protocol presented in Section 4 were necessary in order to integrate scalable video streams. They can either be classified as concerning the Push-to-Pull protocol or the layered structure of a video stream. Adaptations to the protocol of Pulsar consider the modified communication between peers, when distributing a scalable video stream. In addition, the internal layered structure of a scalable video stream demands further attention besides the protocol.

5.1.1 Protocol

Theoretically, a scalable video stream could be transmitted via the same overlay structure, which is also used for non-scalable streams. But to fully benefit from the possible advantages of scalable video, the protocol has to consider the fact that peers might request different layers of the same video stream. Thus, the following paragraphs describe those parts of the Pulsar protocol that need to be expanded in order to handle peers requesting different layers.

Neighbor Selection

Each peer within the Pulsar network keeps its own list of neighboring peers (see Section 5.1.2). This group of peers is not only used to select children nodes for pushing packets, but also for exchanging packets during the pull phase of packet distribution. Hence, the composition of this group strongly influences the distribution of packets in the Pulsar network. In order to gradually improve the group of neighbors with respect to the available bandwidth and to adjust to variation within the group, Pulsar provides means for periodically updating the members of the group. Therefore, all neighbors are ordered according to a specific criterion and those neighbors that appear at the end of the list are replaced by other peers.

Thus, the composition of neighbors is determined by two aspects: the strategy for scoring current neighbors and the strategy for scoring candidates for possible new neighbors. In Pulsar both scoring strategies can be implemented separately by the so called *Neighbor Scoring Strategy* and the *Candidates Scoring Strategy*, respectively. Hence, neighbors with a low value according to the Neighbor Scoring Strategy are likely to be replaced by peers that perform well with respect to the *Candidates Scoring Strategy.* For scalable video streams it is important that both strategies also take the number of layers that each neighbor offers into account. In order to fully benefit from the advantages that scalable video offers, two new strategies were devised: *Scalable Neighbor Scoring Strategy* and *Scalable Candidates Scoring Strategy.*

The *Scalable Neighbor Scoring Strategy* has to consider the fact that only neighbors from the same or higher layers can provide all packets needed to play a specific layer. Although for example neighbors from the base layer can assist in constructing the base layer, their contribution is not sufficient to receive any enhancement layer. Since the *Scalable Neighbor Scoring Strategy* determines which neighbors are replaced by new peers, it is therefore important to ensure that at least one peer from the same or higher layers remains in the group of neighbors.

In particular, the *Scalable Neighbor Scoring Strategy* of Pulsar implements this constraint using a little trick. Usually all peers are scored according to their upload capacity. Only if one neighbor is the last one from the group of neighbors that offers the same or a higher layer, this peer obtains a virtual bandwidth boost. This boost guarantees that the *Scalable Neighbor Scoring Strategy* never chooses this neighbor for replacement.

Candidates Selection

The *Candidates Scoring Strategy* used by Pulsar for non-scalable video streams, relies on the computation of the packet Round Trip Time (RTT) to neighbor candidates. Thus, locality is taken into account in selection new neighbors by preferring peers with a shorter RTT. The reason behind using RTT is that information about the available bandwidth is not known prior to any packet exchange over a longer period of time.

In case of the *Scalable Candidates Scoring Strategy* the number of layers plays an even more important role. Generally all peers strive to connect to peers, who are in the same or higher layers. Therefore, initially only peers from the same or higher layers are considered as neighbor candidates. Within one layer the candidates are scored accoring the RTT similar to non-scalable streams. Only if no more peers from the same or higher layers are available, peers from lower layers are chosen as new neighbors.

Since the source of a scalable video stream determines the maximum number of layers, this *Scalable Candidates Scoring Strategy* aims at distributing packets first to the higher layers and subsequently also supply lower layers. Figure 5.1 illustrates this concept on an example with three layers (the source is marked with a white point).

The idea behind this *Candidates Scoring Strategy* is two-folded.

- First, it can be assumed that peers in the highest layer have a high bandwidth at their disposal. Therefore, distribution among them can be conducted in a fast and efficient way. As soon as all peers in the higher layers are reached, they can further support colleagues from layers underneath. In this way the packets are rapidly distributed to as much peers as possible, which helps in reaching every peer in a short period.

- Second, without a preference for peers in the same (or higher) layers, clustering of peers that only request the base layer becomes a threat. This happens due to the fact that only peers from higher layers can entirely serve peers from lower layers and not the other way around. Peers in the lowest layer only receive packets from the base layer of the video stream and therefore cannot support any requests for

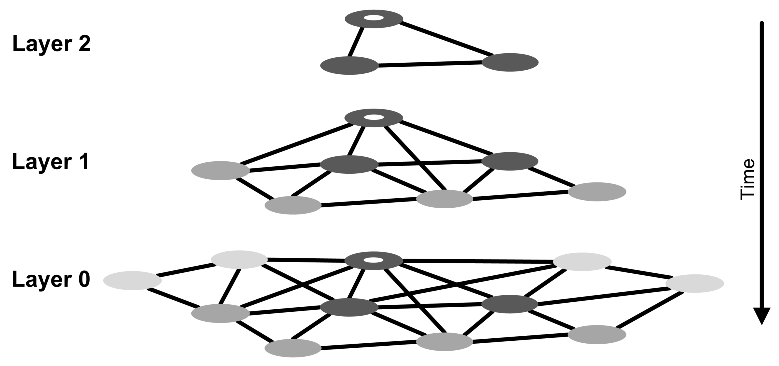


Figure 5.1: SVC Neighbor Selection

enhancement layer packets. Thus, for peers that need more than just the base layer it is crucial to connect to enough neighbors from the same or higher layers.

Incentives

Essentially the basic incentive mechanisms of Pulsar outlined in Section 4.2 also work fine for scalable video streams. However, the varying importance of layers within a scalable video stream can be incorporated into the *tit-for-tat*-strategy. Generally speaking, Pulsar implements the *tit-for-tat*-mechanism by assigning each packet a so called *payback ratio*. The higher this ratio is the more packets one peer can expect to receive in return for offering one packet. In other words, *payback ratio* influences the "motivation" for sharing packets by determining their "prices".

The *tit-for-tat*-mechanism can further be used to assign packets from different layers corresponding importance. Two contrary strategies for this purpose are feasible, depending on which layers are regarded most valuable:

- One strategy would be to conform to the layered structure of the scalable video stream and consider the base layer most important, since it is essential for all higher layers. In doing so, packets from the base layer would be assigned higher *payback ratios* than the ones from enhancement layers. For example the *payback ratio* could double from one layer to the next higher layer, leading to an exchange rate, that allows to receive two enhancement packets instead of one base layer packet. This strategy clearly favors weak peers, since the base layer packets they receive during the pushing phase are more valuable in the subsequent *tit-for-tat*-pull phase. Thus, it is easier for weak peers to obtain all base layer packets they need. However, at the same time strong peers are not motivated to offer their packets from enhancement layers, which could hinder the distribution of enhancement packets.

- Due to the problems of the first solution and the fact that stronger pees also need more packets to display high layers the allocation of *payback ratios* to layers could be reversed. This strategy would follow the idea that enhancement packets are rare and therefore more valuable than packets from lower layers. Hence, strong peers have no problems to obtain all packets up to the highest layer, while weak peers have to struggle to complete their base layer.

The decision between those two strategies can be chosen depending on the bandwidth distribution of the peers and other parameters. Additionally, more test runs are necessary in Pulsar to study both solutions more profound and identify their advantages and disadvantages. From a solely theoretical perspective the first strategy seems more robust and fair concerning the overall distribution of packets for all layers and peers.

5.1.2 Layered Video Stream

In addition to the protocol aspcets the internal layered structure of a scalable video stream bears further challenges for Pulsar in comparison to single layer video streams (i.e. H.264/AVC). For the remaining of this report the term "frame" refers to a set of layers that together form a complete picture of the final video sequence.

Parts

Pulsar employs for each non-scalable video stream exactly one overlay structure and consequently also only one set of strategies for requesting and notifying packets. This concept proves too rigid for a scalable bit stream containing different layers, since it would be favorable to adjust those strategies for each layer individually. Thus, the concept of an overlay structure was expanded to cope with several layers. Now, each overlay can be comprised of several so called parts. Each part is responsible for distributing one layer. An individual set of strategies can be assigned to each part, which allows for specific strategies targeted at each layer. Although all parts of a scalable video stream employ their own set of strategies, they are all united under the same overlay structure. Accordingly, all parts rely on a unique list of neighbors as well as on a unique strategy to update them. This fact ensures that the overall overlay stays connected and does not break apart into smaller sub-group for each layer. The basic structure of the modified overlay is shown in Figure 5.2.

The concept of parts can further be generalized by the fact that their application is not restricted to layers of a scalable video stream. Also other data types that are related to the scalable video stream can be conveyed via parts. This is especially important for meta data such as general information about the stream or security information.

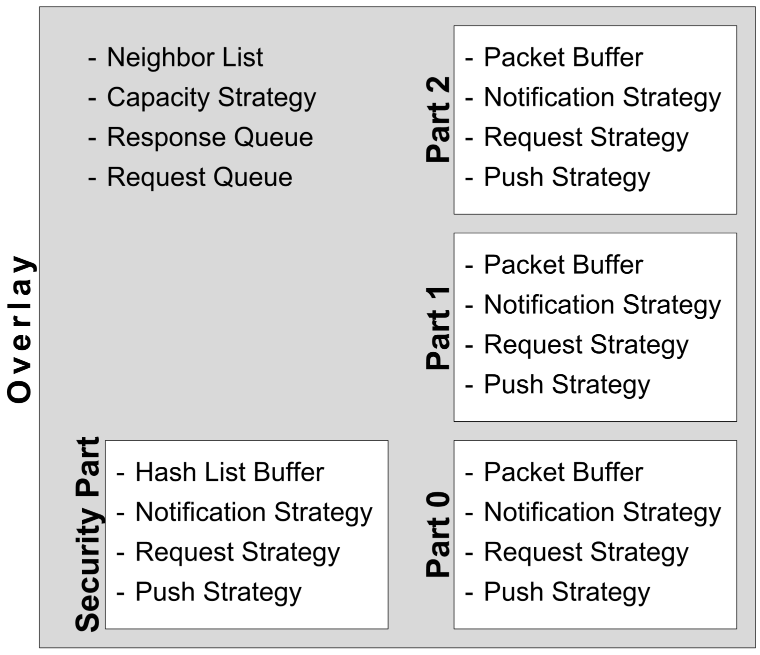


Figure 5.2: One overlay containing three layer parts

Packet Buffer

On the receiver side Pulsar collects all data packets of a non-scalable video stream in a buffer. There all incoming packets are sorted; missing packets are requested and after a specified time period the available packets are finally handed over to a buffer reader.

Those buffer readers are responsible for providing an interface for fetching available packets from the buffer. The general concept of buffers and buffer readers is outlined for three layers in Figure 5.3. Due to the modifications of overlay parts (Section 5.1.2) the buffer for incoming SVC packets has to be modified as well. Similar to the concept of parts, each layer handles incoming packets in its individual buffer. Thus, it remains the task of combining those buffers to form a single output stream. This is realized by an additional buffer reader, which functions as a wrapper around all layer buffers and merges their output to a single output stream.

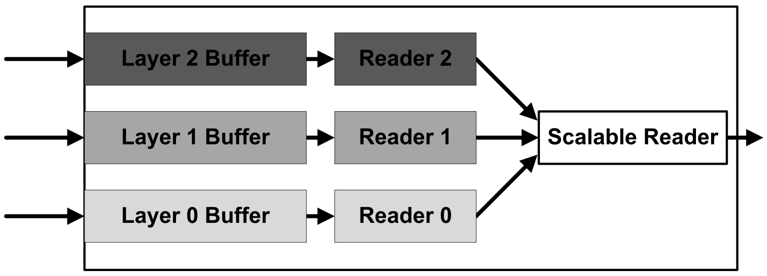


Figure 5.3: Three Part Buffers

Scalable Payload

H.264/AVC uses a basic data structures called Network Abstraction Layer (NAL) Units to divide the encoded video into data packets [55]. As an amendment to H.264/AVC the SVC standard employs this concept as well and in addition defines its own NAL unit types [62], [63]. For all following considerations it is assumed that each layer within one frame is allocated exactly one NAL unit. Pulsar on its part encapsulates data into so called StreamPackets before sending them over the network. Therefore, a new payload type for StreamPackets was introduced: ScalablePayload. This payload type is designed for the purpose of conveying scalable media content (especially scalable video). In the header of the ScalablePayload the following information is bit-wise encoded.

Pseudocode 1 Scalable Payload Header

```
Bit Size        Name            Comment
-------------   -------------   -------------
1               firstComplete
1               lastComplete
6               nPackets
16 * nPackets   refSeqs         Golomb variable length coding
6               refOffsets
12 * nPackets   dataOffsets
1  * nPackets   contentIds      more possible in the future
3  * nPackets   temporalIds     Golomb variable length coding
```

The first two bits (`firstComplete` and `lastComplete`) indicate whether the first or the last) NAL unit of the StreamPacket is part of a large NAL unit or completed. If `lastComplete` is 0, the next StreamPacket should have `firstComplete` also equal to 0. Otherwise parts of a divided NAL unit are missing in between. The next field `nPackets` counts the number of NAL units included in the StreamPacket and together with the previous two bits they form the first byte of the ScalablePayload header with the most important information.

`refSeqs` and `refOffsets` store references to StreamPackets in the next higher layer (Section 5.1.2). For each NAL unit included in the StreamPacket `refSeqs` holds the sequence number of the StreamPacket that contains the next higher NAL unit. This information is important for the scalable reader (Section 5.1.2) to reconstructe all layers from the base up to the last enhancement layer. The references are likely to increase only by one or at most a few steps from one NAL unit to the next. That is why only the first value is directly encoded and for all subsequent references only the difference to the prior value is conveyed. Furthermore, *Golomb* variable length entropy coding [64] is employed to further reduce the necessary bits. In addition to the sequence number references, `refOffsets` points to the first NAL unit in the next higher StreamPacket that depends on the current StreamPacket. This information is necessary for recovery after packet losses (see next next Section 5.1.2).

In order to safe further bytes ScalablePayload does not separate NAL units using the usual H.264/AVC three bytes delimiter `001`. Instead `dataOffsets` indicates the limits between several NAL units. The following bit `contentIds` is yet always equal to 0, but in the future it is intended to distinguish between audio and video data. In addition `contentId` could be expanded to comprise more than one bit in order to support other content types as well (e.g. speech, meta information or subtitles). At the end of the header, the fields `temporalIds` signal to which temporal layer each of the following NAL units belong. This information enables the extraction of a specific temporal layer without the need for parsing any of the NAL units. The difference between the values for `temporalIds` are also likely to differ only by one. Therefore, the same variable length coding schema as for `refSeqs` is adopted.

Packeting of Scalable Payload

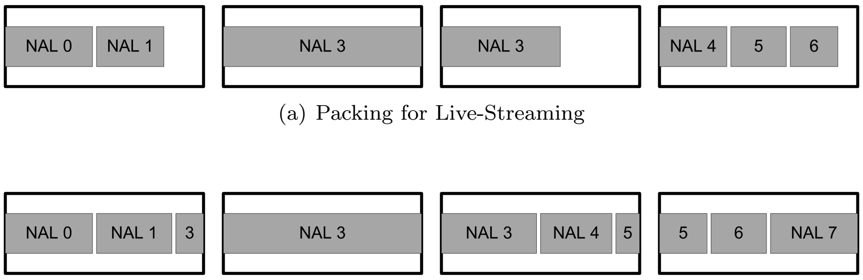
Besides the payload a new method for packing SVC NAL units into StreamPackets had to be devised. For this propose different techniques tailored to specific needs were developed. In all cases the maximum size of a StreamPacket is assumed to be 1350 bytes.

The first solution fills the StreamPackets with NAL units until the next NAL unit does not fit in any more. Then a new StreamPackets is started with the complete new NAL unit at the first position. If the size of a single NAL unit is larger than one stream packet (most often the case at I-frames), the NAL unit is partitioned among several StreamPackets. Finally, the rest of a divided NAL unit is allocated a separate StreamPacket (Figure 5.4(a)). The `firstComplete` and `lastComplete` fields of the ScalablePayload (see 5.1.2) signal if the StreamPacket includes parts or complete NAL units. This simple and robust packing technique fits the needs of Live Streaming. On the one hand packets are not completely filled, which produces a certain amount of overhead, but on the other hand it limits the aftermath of lost StreamPackets.

In some cases the varying size of StreamPackets can turn out less useful. This is especially the case for On-Demand Streaming where the whole video stream is stored at the end user's hard disk. Random access of this file is simplified, if StreamPackets of constant size are used for storing.

Therefore, a second method for packing SVC NAL units into StreamPackets was devised. The difference to the first packing method is that StreamPackets are entirely filled up untill the maximum capacity is reached (Figure 5.4(b)). Thus, NAL units are not only divided in cases where they exceed the size of one StreamPacket, but also if the remaining space in a StreamPacket can be completed by parts of the next NAL unit. Due to the fact that this method utilizes the StreamPackets in a more efficient way, the average overhead for each NAL unit is reduced. However, if a single StreamPacket gets lost, also NAL units from other StreamPackets can be affected, since they were divided among several StreamPackets.

For an expansion of the scalability functionality to handle different temporal resolutions in addition to quality layers, a third packing strategy might be of interest. Thereby, the coding order of frames is considered during the packaging of NAL units. In order to enable a hierarchical prediction structure, the frames need to be encoded in a spe-



(a) Packing for Live-Streaming

(b) Packing for OnDemand-Streaming

Figure 5.4: Allocation of NAL units to StreamPackets

cific succession that mostly does not match their actual order within the video sequence (Figure 3.2(a)). For each *Group of Pictures* first the frames of the lowest temporal layer are encoded, because all following frames depend upon them.

The two packing methods discussed so far did not consider those dependencies between frames. The only criterion was the remaining space in the StreamPacket to be filled. However, in order to offer several temporal resolutions, it is important that temporal layers can easily be extracted from the complete video stream. This is only possible, if frames from different temporal layers are not placed in the same StreamPacket. Therefore, the temporal layer of each NAL unit has to be considered during packing of StreamPackets. Figure 5.5 illustrates this idea on the same example already used in Figure 3.2(a). The difference is that frames are now ordered according their encoding succession and the numbers underneath indicate the playback sequence numbers. Of course, this method does not use the capacity of StreamPackets in an optimal way, but in return different temporal resolutions can be extracted without unpacking any StreamPacket.

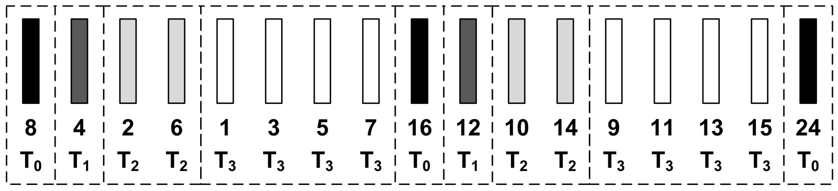


Figure 5.5: Packing of Frames according their Temporal Layers

Reference Structure

After receiving StreamPackets from different layers they are rearranged by the scalable reader (Section 5.1.2) according to the information found in the header (Section 5.1.2). Every ScalablePayload includes a reference to the related StreamPacket in the next higher layer, as well as an offset to the right NAL unit within this StreamPacket, as illustrated in Figure 5.6. With this information the order and dependencies between the NAL units from different layers can be reconstructed.

Even in case of packet lost, the remaining NAL units can be reassembled as illustrated in Figure 5.7. In this example the second StreamPacket from Layer 1 was lost during transmission. Since the NAL units of frame number 2 and 3 were included in this StreamPacket, only the base layer can be used for those frames. As soon as new StreamPackets are available again in Layer 1 (at frame number 4), the quality of the output video gets back to the highest layer. This example furthermore shows the need for the `refOffsets`-field of the scalable payload (see 5.1.2). In order to recover at Frame

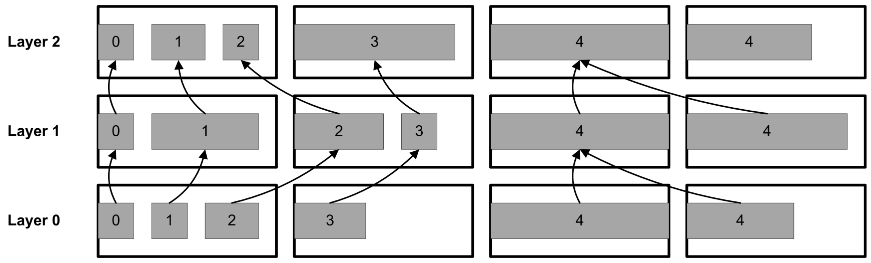


Figure 5.6: References between NAL units from three Layers

4 from the missing StreamPacket the receiver not just needs the reference to the StreamPacket that includes Frame 4, but also its position inside this StreamPacket. In cases of missing StreamPackets from the base layer, all of the included frames have to be skipped completely. This is due to the layered structure of SVC, where the base layer is essential for all enhancement layers.

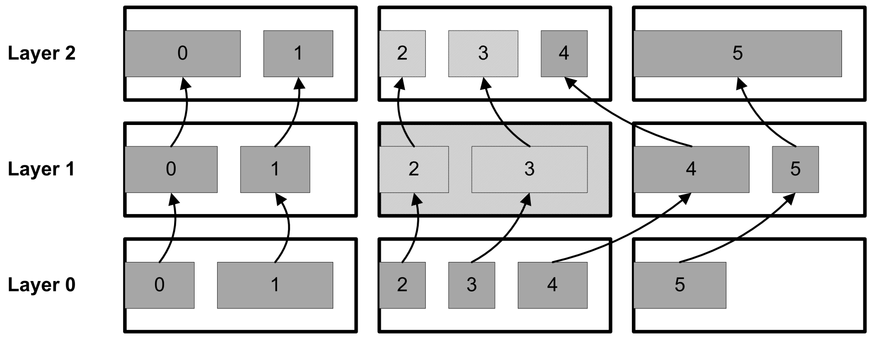


Figure 5.7: Recovery after lost SreamPacket

Since all layers are encoded as MGS layers, the whole SVC stream is robust against lost NAL units from enhancement layers. As pointed out in Section 3.2.3, MGS streams can be scaled on a packet base level, because all layers rely on the same motion prediction loop. Hence, single packet losses do not cause the complete layer to collapse. This benefit simplifies the task of error resilience, since no special care has to be taken on detecting lost enhancement layer packets. However, if packets from the base layer get lost, the complete frame has to be skipped (even if enhancement packets are available), as well as all frames that are dependent via motion prediction.

5.2 Modifications concerning JSVM

The first attempt to implement an own SVC decoder in order to use it in Pulsar turned out as too time consuming. Although, some parts of the already written code could be reused for further purposes (e.g. the code for parsing NAL units in a SVC encoded video stream). Due to the limited time we decided to rely on the JSVM software and integrate its code into Pulsar.

5.2.1 Quality Scalability

Before integrating scalable video into the Pulsar streaming software various test runs were conducted with the SVC reference software called Joint Scalable Video Model (JSVM) [16]. The results are presented in Section 6.1. After those tests we decided to first concentrate on quality scalability as a starting point, with the following motivation.

When scaling a video on the basis of its quality, the consumer may notice the lower bit rate by block patterns or other visual artifacts. However, the spatial and temporal resolution of the video sequence is kept intact, which guarantees a smooth playback. Furthermore, with medium grain scalability (MGS) the choices of different bit rates is not restricted to the number of layers and the bit rate can be scaled on a packet based level. This feature essentially improves the flexibility of the scalable video stream and at the same time makes it to some extent robust against lost packets. Although other scalability options (namely spatial and temporal scalability) as well offer interesting possibilities, quality scalability seems to best fit the requirements of a peer-to-peer environment.

5.2.2 Temporal Scalability

In contrast to Spatial and Quality Scalability, a standard H.264/AVC video stream can already include different frame rates. Since hierarchical B-frames (Figure 3.2) can be encoded by the sole use of H.264/AVC concepts, regular non-scalable decoders are also capable of handling temporal scalable video streams. Especially for MGS streams temporal scalability forms an integral part of the primarily quality scalable video stream. This is due to the fact that all frames from the lowest temporal layer are encoded as key frames (see Section 3.2.3). Motion prediction for key pictures is conducted in the base quality layer in contrast to all other frames, where the highest quality is used for this purpose. Therefore, every MGS stream offers quality and temporal scalability at the same time. In order to make use of the temporal layers special methods for packing and signaling those layers are needed.

5.2.3 Decoding or Rewriting

Another interesting question that came up during testing the JSVM software was the relation of SVC and basic H.264/AVC. Since Pulsar is already working with the common H.264/AVC decoder of *FFmpeg* [65], it would be nice to expand its functionality to also cope with scalable video. In this way the redundancy of two parallel decoders - one for single layer H.264/AVC and one for SVC - could be avoided. One way to achieve this goal would be to directly integrate scalable video functionality into the existing code of *FFmpeg*. Our efforts in this direction are still not finished yet, but under continuous progress.

This report however concentrates on a second solution. Thereby a scalable bit stream is first transformed to a regular H.264/AVC stream and subsequently handed over to the *FFmpeg*-decoder of Pulsar (see Figure 5.8). The specification of SVC considers such rewriting concepts [66], which will be outlined in the following paragraph.

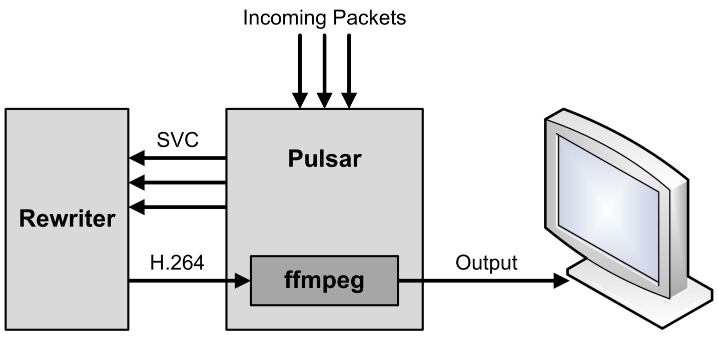


Figure 5.8: SVC-to-H.264 Rewriter

5.2.4 Rewriter

The basic idea of rewriting a SVC video is to encode the contained layers in a way that merging them to a H.264/AVC bit stream only requires simple and fast operations. This is possible if all operations can be completed in the transform coefficient domain without having to entirely decode each layer. The scalability dimensions present in the SVC stream determine the complexity of the rewriting process.

Since encoding and decoding of hierarchical B-frames is just as well possible with pure H.264/AVC means, a solely temporal scalable video stream already represents a valid H.264/AVC stream. Thus, a common H.264/AVC decoder can handle different temporal layers within a video stream, which makes rewriting needless. For spatial scalability things are not that simple. The fact that each spatial layer represents a different spatial resolution complicates the attempt to merge all layers to a single H.264/AVC stream. Merging spatial layers would require almost complete decoding of each layer with subsequent re-encoding to a H.264/AVC stream. That is why rewriting spatial scalable video streams is not supported by the SVC standard. In case of the third scalability dimension, concerning the quality, rewriting is possible, as long as certain constraints are regarded. Especially three modifications to the syntax of a basic SVC bit stream are necessary to enable fast rewriting of quality layers. Those changes are briefly explained in the following paragraphs, while the reader is referred to [66] for an in-depth discussion.

- The first modification concerns residual predicted macro blocks (Section 3.2.2). Normally those kinds of blocks take the residual information from the reference layer, inverse transform it back to the spatial domain and finally use the result as a prediction for the residual in the current layer. Since in H.264/AVC residual information is also stored in the frequency domain, for the purpose of rewriting it makes more sense to conduct residual prediction directly in the frequency domain.
- Additionally, also intra predicted macro blocks require modifications in order to transform them into H.264/AVC ones. As described in Section 3.2.2 intra predicted macro blocks need to completely decode the reference layer in order to use it as prediction. To avoid this step inter-layer intra prediction is omitted and normal intra prediction is performed in each layer separately. This simplifies the transformation into non-scalable intra macro blocks.
- Especially for MGS video streams a third restriction becomes relevant. The fact that for key pictures of a MGS stream the base layer representation is employed as reference for motion prediction handicaps the rewriting task. In the rewritten H.264/AVC stream it is not longer possible to distinguish between motion prediction from the base layer (key pictures) and the highest enhancement layer (non-key pictures). Therefore, key pictures are not allowed in rewritable MGS streams. Without key pictures problems due to drift (Section 3.2.3) become difficult to handle. However, our test runs regarding drift revealed no severe visual faults due to this phenomenon even without key pictures. Nevertheless we decided to rely on periodic I-frames in order to limit any possible impacts caused by drift.

If all the restrictions are considered during encoding, the final quality scalable bit stream can easily be rewritten to a valid H.264/AVC video. However, this comes at the price of a slightly decreased coding efficiency. The impact of the described modifications on the final bit rate is studied in the evaluation part of this report (Section 6.1.3).

5.2.5 JNI Interfaces

Two obstacles were to overcome in order to use the JSVM rewriter in Pulsar:

First, the gap between two programming languages had to be closed: Pulsar is implemented in Java in contrast to JSVM which is written in Visual C++. To let both applications collaborate with each other, we made use of the so called Java Native Interface (JNI) [67]. This library provides interfaces that allow Java code running in the virtual machine (JVM) to call functions written in a different programming language (i.e. native code like C++, C or other implementations). Also the opposite direction, a native program calling Java code, is possible through the JNI.

As far as it concerns the integration of the JSVM rewriter into Pulsar, we employed both the writing and reading functionality of the JNI. The first one for sending packets received by a Pulsar peer to the rewriter and the second one for subsequently collecting the rewritten H.264/AVC frame. The basic concept is seen in Figure 5.8. Direct Byte Buffers are used as data structures for actually exchanging bytes between both applications (see Pseudocode 2).

Pseudocode 2 Rewriter Interface for waiting on available NAL units (C++)

```
// finding method for fetching next packet from Pulsar
fetchPacketMethod* = GetMethodID("fetchNextNALunit");

// actually waiting till next NAL unit is available
javaObject* nalUnitByteBuffer = CallMethod(fetchPacketMethod);

// get address of new NAL unit
unsigned char* nalUnitAddress = GetByteBufferAddress(nalUnitByteBuffer);
```

Second, the code of the JSVM rewriter had to be modified in order to work with a consecutive stream of video data. Before, the software assumed that a complete and finished video file is available. In our solution the rewriter is now running parallel to Pulsar waiting to rewrite one frame as soon as it is received. Code snippets for this function are listed below (see Pseudocode 3).

Pseudocode 3 Pulsar Interface for sending available NAL units to Rewriter (Java)

```
public ByteBuffer fetchNextNALunit(){

  ArrayList<ByteBuffer> availableNalUnits;

  while(true){
    if(availableNalUnits.size > 0){
      availableNalUnits.returnFirstInLine();
      availableNalUnits.removeFirstInLine();
    }
  }
}
```

For the actual integration into Pulsar a new *FFmpeg*-codec was generated, which uses the rewriter to transform SVC NAL units into H.264/AVC ones. Therefore, *FFmpeg* can handle SVC streams by simply utilizing the new rewriter-codec in connection with the regular H.264/AVC decoder. Furthermore, the interface outlined above is not restricted to the JSVM rewriter. It could equally be expanded for encoding or completely decoding (not just rewrite) SVC bit streams. Nevertheless, the performance issues of the JSVM implementation outlined in Section 7.1 should be pointed out as well.

Chapter 6

Evaluation

6.1 SVC Evaluation

All of the following test runs were conducted with the Joint Scalable Video Model (JSVM) - Version 9.12.2 - which serves as the reference software behind the SVC standard. It is maintained by the Joint Video Team (JVT) and freely available over the Internet [16].

After conducting a few test runs with JSVM we recognized that the provided test sequences [68] are not representative enough for our purpose. In some test cases their short length of only a few seconds was not sufficient to produce stable results. Therefore, we created our own test sequence on the basis of the open source movie *Elephants Dream* [69] and the Trailor for the movie *Michael Clayton*.

Pseudocode 4 Main Configuration File for three MGS Layers

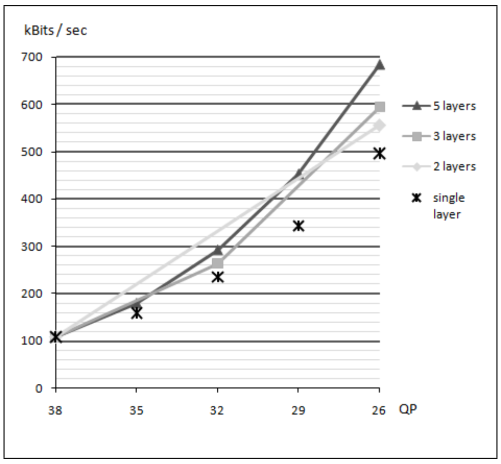
```
# JSVM Main Configuration File

OutputFile              ed/ed_400x224.svc    # Bitstream file
FrameRate               25.0                 # Frame rate
FramesToBeEncoded       1749                 # Number of frames
GOPSize                 16                   # GOP Size
IntraPeriod             32                   # Intra Period

BaseLayerMode           1                    # Base layer mode
SearchMode              4                    # Search mode
SearchRange             32                   # Search range

CgsSnrRefinement        1                    # 1: MGS; 0: CGS
EncodeKeyPictures       1                    # 0:none, 1:MGS, 2:all
MGSControl              2                    # ME/MC for non-key pics

NumLayers               3                    # Number of layers
LayerCfg                layer0.cfg           # Layer 0 config file
LayerCfg                layer1.cfg           # Layer 1 config file
LayerCfg                layer2.cfg           # Layer 2 config file
```

6.1.1 Single Layer vs. Multiple Layers

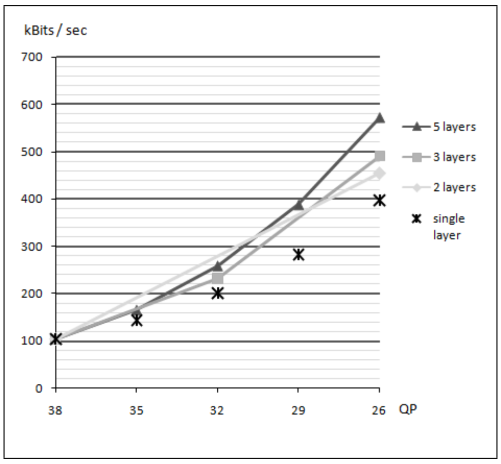
The first question studied during the evaluation was concerning the overhead of scalable video in comparison to non-scalable video streams. Therefore, several SVC test sequences with different numbers of quality layers (MGS) were compared to single layer H.264/AVC. In all test cases a resolution of 400 x 224 pixel was used with similar parameters to the ones presented in Pseudocode 4. All layers were encoded at a constant frame rate of 25 frames/sec. Furthermore, SVC-to-H.264/AVC rewriting ability was disabled (`AvcRewriteFlag 0`) and inter-layer prediction was set on to adaptive (`InterLayerPred 2`).

The most important parameter during encoding a quality scalable bit stream represents the quantization parameter (called QP). This parameter influences the quantization of transform coefficients by specifying the quantization step size. Thus, a smaller QP value increases the number of quantization levels and consequently sustains more details of the original video in the encoded version. In particular, an increment of QP by 1 corresponds to a larger quantization step size of approximately 12% [70] and a corresponding decrease in bit rate of about the same percentage. Hence, a difference of 6 QPs should lead to circa a doubling of bit rate ($1.12^6 = 1.97$).

Figure 6.1 illustrates the overhead induced by SVC, by comparing different QP values with their corresponding bit rates. For both test sequences (*Elephants Dream* and *Lost*) the bit rates of the non-scalable bit streams are illustrated as single points. In contrast to SVC streams, they are not connected via a curve in order to clarify that they represent separate streams. Each of these H.264/AVC streams was encoded with a different QP ranging from 38 to 26. Thus, for H.264/AVC streams the lowest bit rate (128 kBits/sec) forms roughly 1/4 of the highest one (512 kBits/sec).



(a) *Elephants Dream* Test Sequence



(b) *Lost* Test Sequence

Figure 6.1: SVC overhead in comparison to H.264/AVC

Taking a look at the SVC video streams (illustrated as solid curves in Figure 6.1), it can be seen, that in all cases the lowest layer (i.e. the base layer) comprises the same bit rate as the base H.264/AVC version does. This is not surprising since the base layer of a SVC video always represents a valid H.264/AVC stream. However, when adding more layers to the SVC stream, a certain amount of overhead compared to H.264/AVC becomes apparent.

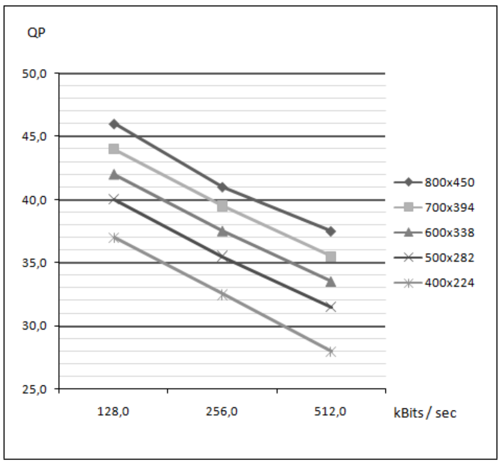
The most important characteristic of the three SVC streams illustrated in addition to the H.264/AVC stream is their number of MGS layers. The more different bit rates a SVC stream offers, the higher is its overhead in comparison to the corresponding H.264/AVC version. When concentrating on the highest bit rate (i.e. QP of 26) the following overhead (as percentage) can be measured for the *Elephants Dream* test sequence:

12%, 22% and 40% for two, three and five layers respectively. Whereas the corresponding results for the *Lost* sequence reveal 13%, 24% and 44% of overhead. Thus, as a rule of thumb it can be stated that one additional enhancement layer yields approximately 12% of overhead. This statement also holds true in cases of lower bit rates. For example SVC layers of the *Elephants Dream* sequence encoded with a QP of 32 bear an overhead of about 12% and 24% (3 and 5 MGS layers respectively) in comparison to the corresponding H.264/AVC stream at a similar QP.

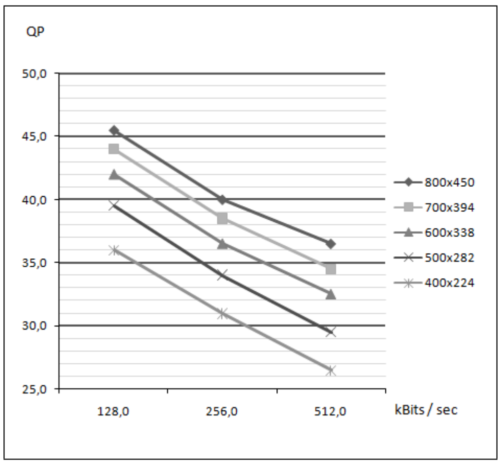
6.1.2 Quality Parameters

The aim of the next test runs was to find the right QPs for encoding a three-layered MGS bit stream. The layers were supposed to encompass the following bit rates: 128 kBits/sec, 256 kBits/sec and 512 kBits/sec. In order to compare different resolutions, the test runs were conducted on video sequnces with constant aspect ratio but varying frame sizes. All other parameters were chosen similar to the previous example (Section 6.1.1) and to the ones listed in Pseudocode 4.

Figure 6.2 presents the results for five different resolutions of each test sequence. For each MGS layer on the horizontal axis the corresponding QPs are measured on the vertical axis. Obvious is the constant trend of declining QPs with increasing bit rate. This is not surprising since smaller QPs decrease quantization step size and consequently lead to higher bit rates. But looking more closely some other interesting aspects emerge.



(a) *Elephants Dream* Test Sequence



(b) *Lost* Test Sequence

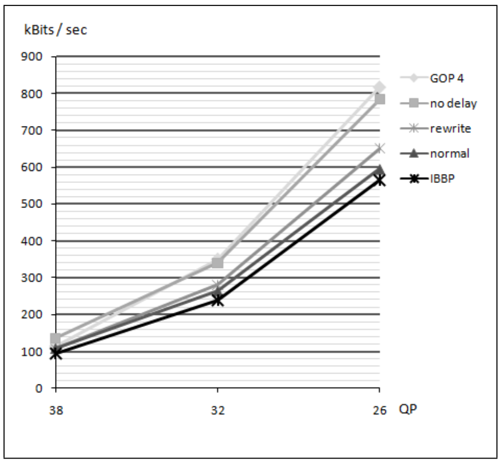
Figure 6.2: Five different resolutions, each with three MGS layers

One interesting question of Figure 6.2 is the difference in QPs from one layer to the next. For both test sequences those differences fall into a constant interval from 4.5 to 5.5 (with slightly larger differences on average for the *Lost* test sequence). The actual interesting aspect about this fact is that while the bit rates double from one layer to the next (128 kBits/sec to 256 kBits/sec and 512 kBits/sec), the corresponding QPs differ in less than 6 QPs. As noticed in the previous example, twice as much bit rate in a H.264/AVC stream allowed for the QP to decrease about 6 levels. For SVC streams this is apparently not the case. Responsible for this is the overhead induced by SVC. Hence, only an improvement of roughly 5 QPs is possible for a doubled bit rate. Referring to the prior comments that a step of 1 in the QP parameter relates to variations of the bit rate by approximately 12%, the following rule of thumb can be stated: one new MGS layer with twice the bit rate imposes an overhead of about 12% to the bit stream. This result matches similar findings of the previous example in Section 6.1.1.

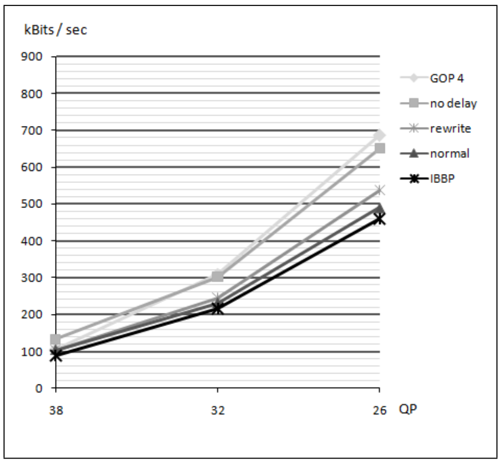
Another notable aspect of the Diagram 6.2 is the comparable large difference in QP from the lowest resolution (400 x 224) to the next higher one (500 x 282). This can be explained by the fact that the JSVM encoder always expands the resolution of the input sequence to a multiple of the macro block size (16 x 16 pixel). Therefore, 400 x 224 is the only resolution that is kept intact, while all other frames need to be expanded in order to form a multiple of 16 x 16.

6.1.3 Varying Parameters

The objective of the third test scenarios was to analyze the impact of varying encoding parameters on the coded bit stream. Therefore, five different MGS streams were encoded in order to compare their final bit rates. All streams encompassed 3 MGS layers with constant quantization parameters (QPs) of 38, 32 and 26. Again the test runs were conducted on two different test sequences: *Elephants Dream* and *Lost*.



(a) *Elephants Dream* Test Sequence



(b) *Lost* Test Sequence

Figure 6.3: Varying parameters for a three layered MGS stream

As a starting point served a three layered MGS stream encoded using the same parameters as in the previous test scenario (Pseudocode 4). Since also the same values for QP were chosen, this video is identical to the three layer version of the previous example with exactly the same bit rates. Starting from here specific encoding parameters were altered to study their impacts on the output bit rate.

As mentioned in the Section 3.2.1 about temporal scalability, a hierarchical prediction structure can still be obtained, while avoiding a structural delay in the decoding process. Such a prediction structure avoids references to future frames (illustrated for example in Figure 3.2(b)) and therefore only employs I or P-frames. Accordingly, this prediction structure is sometimes referred to as: IPPP. The advantage of no delay during decoding comes at the price of a lower coding efficiency and subsequently a higher bit rate. The actual impact on the bit rate can be seen in Figure 6.3(a) and Figure 6.3(b). Around 30% (±5%) more bits per second are necessary in comparison to normal hierarchical B-frames.

The next test runs again concentrated on the prediction structure of the encoded SVC stream. The group of picture size (GOP) (see Section 3.2.1) was reduced to 4 frames, while all other parameters were kept constant (hierarchical B-frames with I-frames every 32^{nd} frame). The advantage of this prediction structure is that negative impacts due to lost reference frames or discarded packets is limited to less frames, which makes the video sequence more robust against interruptions on the transmission link. Though, one disadvantage is that the number of temporal layers is reduced from five to three. An even severer downside reveals the considerable higher bit rate. In the diagrams of Figures 6.3(a) and 6.3(b) those additional bits represent about 40% (±3%) of the reference bit rate (GOP size of 16). Both results from the no delay and the

4-frame GOP test runs show that the structure of hierarchical prediction does have a considerable impact on the final bit rate.

Until now all test sequences were encoded with I-frame updates at every 32^{nd} frame. At a frame rate of 25 frames/sec this corresponds to approximately one I-frame every one and a half second. I-frames as well limit the impacts of lost reference frames. Moreover, they are especially important if no key pictures are encoded in a MGS stream in order to serve as an alternative for controlling the drift. Since key pictures are not allowed for rewriteable MGS streams (5.2.4), I-frames are also important for our system configuration. That is why the differences in sequences with and without periodic I-frames updates were in particular studied during the test runs. As can be seen from the diagrams, the overhead of periodic I-frame updates is not dramatic (less than 5%). Thus, I-frames for drift prevention can idead be inserted in MGS streams without severely impairing the coding efficiency.

The last test configuration also dealt with the rewrite functionality of SVC. Section 5.2.4 pointed out the necessary modifications to common SVC video streams in order to enable rewriting to a regular H.264/AVC video. Since the presented system relies mainly on this rewriting process, the impact of these modifications on the coding efficiency was also investigated during the experiments. The results show that for both test sequences (Figures 6.3(a) and 6.3(b)) the overhead due to the rewriting modifications of Section 5.2.4 is limited to less than 10%. Together with the findings of the pervious paragraph those results prove that the rewriting functionality for MGS streams can be used without sacrificing too much bit rate.

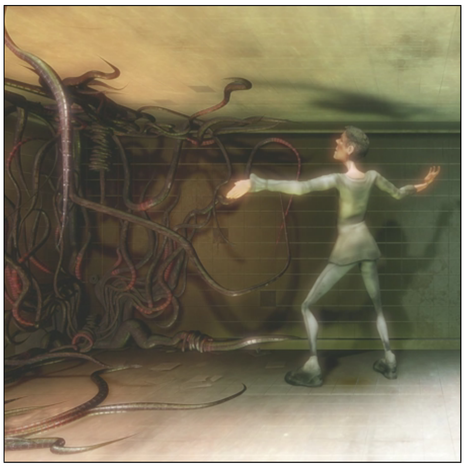
6.1.4 PSNR

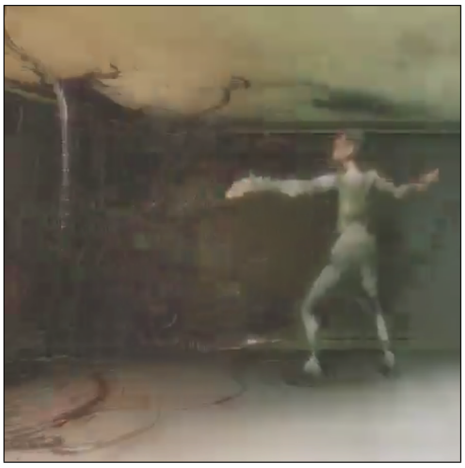
After studying extensively the relationship between quantization parameters (QPs) and corresponding bit rates, the last test scenario focused on their actual impacts on the final video quality. Therefore, outputs from different layers of a scalable video stream were compared. The experiments should consider subjective measurements as well as objective ones to assess the quality of the encoded layers. For a subjective analysis the decoded frames were compared, while the objective analysis relied on the evaluation of the Peak Signal-to-Noise Ratio (PSNR).

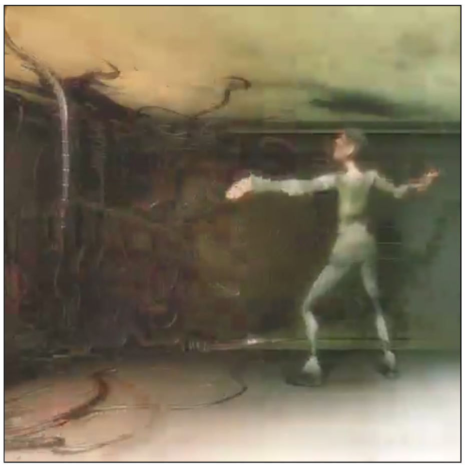
At a bit rate distribution of 128 kBit/sec, 256 kBit/sec and 512 Kbit/sec for each of the three MGS layers, the base layer already provides a decent image quality for a resolution of 400 x 224 pixel. In order to make the differences between the layers more apparent, the resolution of the test sequences was therefore expanded to 800 x 450 pixel. All other parameters were adopted from the test scenario in Section 6.1.2.

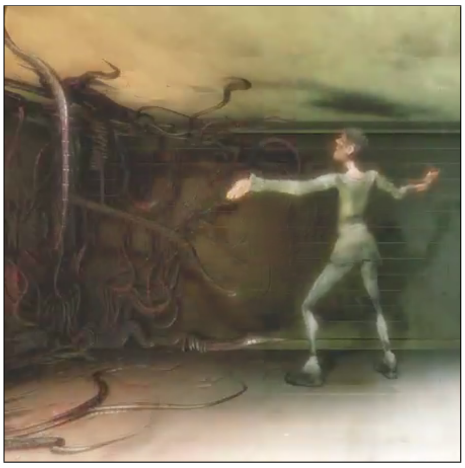
As input stream for this test scenario functioned an uncompressed version of the *Elephants Dream* test sequence (Figure 6.4(a)). The results after compression are illustrated in the next three figures. They show screenshots from each of the three MGS layers encoded at bit rates of 128 kBit/sec, 256 kBit/sec and 512 Kbit/sec. The gradual improvement from the lowest up to the highest layer is apparent. Although the base layer (Figure 6.4(b)) already provides a blurry impression of the scene, it cannot be considered a satisfying quality. Therefore, the higher layers build upon the base layer by further downsizing the quantization step size for improving the image quality. Finally, in the output of the highest layer (Figure 6.4(d)) almost no difference can be recognized in comparison to the one from the non-scalable H.264/AVC stream at the same bit rate (Figure 6.4(e)). However, for all screenshots of decoded frames, especially at a low bit rate, it must be kept in mind that their block patterns were reduced by a post processing deblocking filter. The Figures 6.5 show more screenshots from different MGS layers. This time the frames were enlarged in order point out their varying richness in details.

After the subjective analysis of the output from different MGS layers, those findings are yet to be confirmed by a quantitative examination. For this purpose, the PSNR between the original and the reconstructed video sequences is computed. To simplify matters the PSNR is only studied for the luma channel (Y) of the decoded YUV frames.


(a) Uncompressed Frame


(b) MGS at 128 kBit/sec


(c) MGS at 256 kBit/sec


(d) MGS at 512 kBit/sec

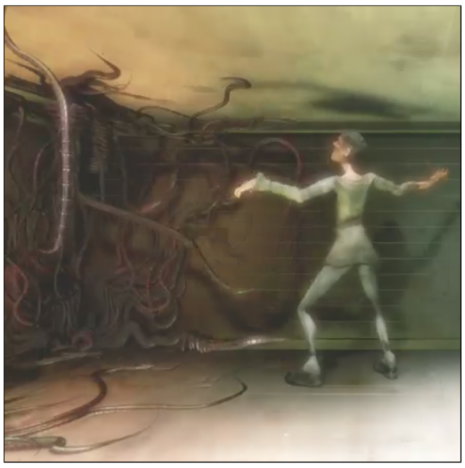
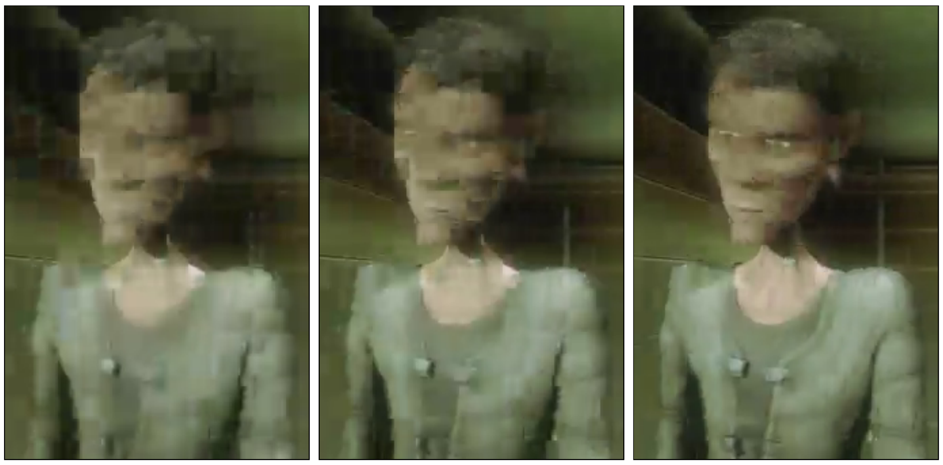

(e) Single-layer at 512 kBit/sec

Figure 6.4: Comparions of different quality layers



(a) 128 kBits/sec (b) 256 kBits/sec (c) 512 kBits/sec

Figure 6.5: Comparions of three different MGS layers

Again, PSNR values in Figure 6.6 for H.264/AVC streams are illustrated as separate points in the diagram to underline their independency from other single-layer streams. As expected, in both cases - SVC and H.264/AVC - the PSNR increases with the available bit rate. Starting at the base layer with a similar PSNR, the differences between scalable and non-scalable streams enlarge up to 2 dB at a bit rate of 512 kBit/sec. Between the lowest and the highest MGS layer an improvement of 5 dB can be determined, which quantizes the enhancements in image quality from Figure 6.4(b) to Figure 6.4(d). Those results are also similar to the ones presented in the evaluation part of [15]. For all consideration of the diagram in Figure 6.6 it is important to keep in mind that the scaling for the bit rate on the x-axis is not constant, but logarithmic.

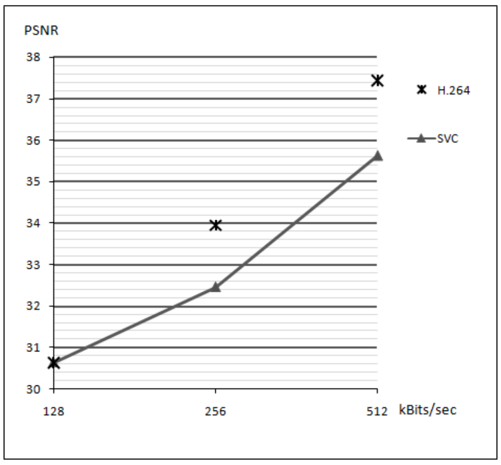


Figure 6.6: Y-PSNR comparison

6.2 Pulsar Evaluation

The foregoing set of test scenarios concentrated on SVC alone and on the impact that certain input parameters play on the scalable video stream. For a better understanding of the advantages that SVC brings to peer-to-peer networks and Pulsar in particular, further test runs were conducted. This second set of test scenarios focused on scalable video data sent over the Pulsar network. Therefore, test cases for assessing the impact of scalable video as a new feature were devised and verified in the Pulsar test bed. For a better control of the data sent over the network, simulated data packets were used instead of actual video data. In doing so, it is possible to test different distributions of data packets to video layers.

6.2.1 Number of decoded bytes

Besides the increase flexibility of scalable video, Section 3.1 also mentioned another advantage of scalable video: prioritization. In representing the encoded video in a layered structure, scalable video offers the possibility to play the video stream at least at a low quality, if the complete video stream is not available.

In order to assess this benefit the same simulated video stream was distributed two times over the same network: the first time as a non-scalable H.264/AVC stream and the second time encoded as a three layered SVC stream. For the H.264/AVC stream a bit rate of 512 kBits/sec (64 kBytes/sec) was assumed, which corresponds to about 600 kBits/sec (75 kBytes/sec) for the SVC stream due to the overhead. The simulated H.264/AVC stream was generated by packets with a constant size of 2560 bytes. Whereas, for the SVC stream varying packet sizes were assumed that relate to packets of a regular SVC stream (i.e. larger packets at low temporal layers due to I and P-frames). In both cases the packet sizes sum up to 64 kBytes/sec and 75 kBytes/sec respectively at a frame rate of 25 frames/sec.

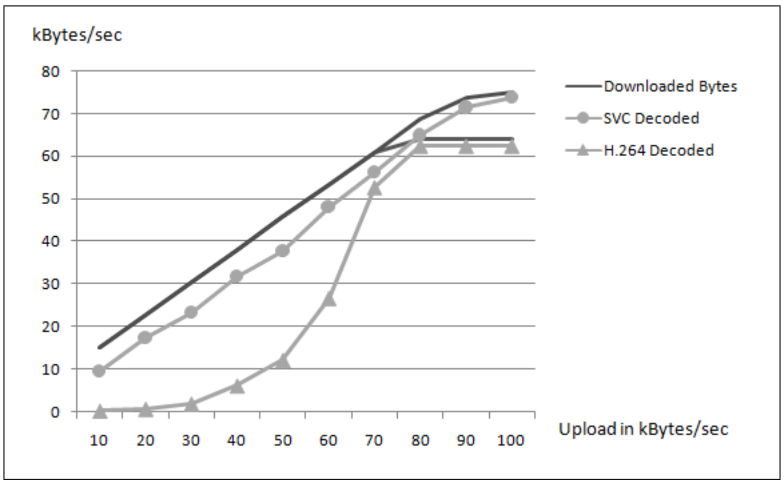


Figure 6.7: Numner of downloaded and decoded bytes

The decisive factor of the results presented in Figure 6.7 is the upload capacity of the peers. This upload speed (measured in kBytes/sec) was assumed to be constant over all of the 50 peers simulated in this experiment. In the diagram the increasing upload capacity is compared with two values: the number of downloaded and the number of decoded bytes. Both values represent the average over all peers. For the H.264/AVC stream a frame was only considered decodable, if all proceeding frames up to the next I-frame could be decoded as well. This prediction structure corresponds to a IPPP succession of frames. Whereas the underlying prediction structure for the SVC stream were hierarchical B-frames (Section 3.2.1). Therefore, at least the base layer of all frames from lower temporal layers had to be available to consider a SVC frame decodable.

Up to the maximum bit rate of the H.264/AVC stream in both cases the same amount of bytes can be downloaded. This value is only restricted by the upload capacity for all peers. The additional bytes beyond 64 kBytes/sec in case of the SVC stream represent the overhead for the scalable information.

When taking a look at the number of decoded bytes a significant difference between the H.264/AVC and the SVC stream becomes apparent. Especially if the upload speed of the peers is strongly restricted, Figure 6.7 reveals that far more data of the SVC stream can be decoded for playback as it is the case with H.264/AVC. This is due to the fact that with scalable video the restricted bandwidth can be used in a more efficient way. While in a non-scalable video stream all bytes have the same prioritization, SVC can concentrate the limited amount of bandwidth to those parts of the video that are necessary to play at least a poor quality or a low frame rate. This is achieved if the low layers (in respect of quality or temporal resolution) of the scalable video stream are downloaded first, before any of the enhancement layers is requested.

Figure 6.8 illustrates the percentage of decodable data in respect to the overall amount of data arriving at the peers. In this case the more efficient use of downloaded bytes is even more apparent. Starting at the lowest upload capacity always more than half of the downloaded scalable video data can subsequently be decoded. For the H.264/AVC stream those values cannot be achieved until upload capacity of the peers reaches about 60 kBytes/sec.

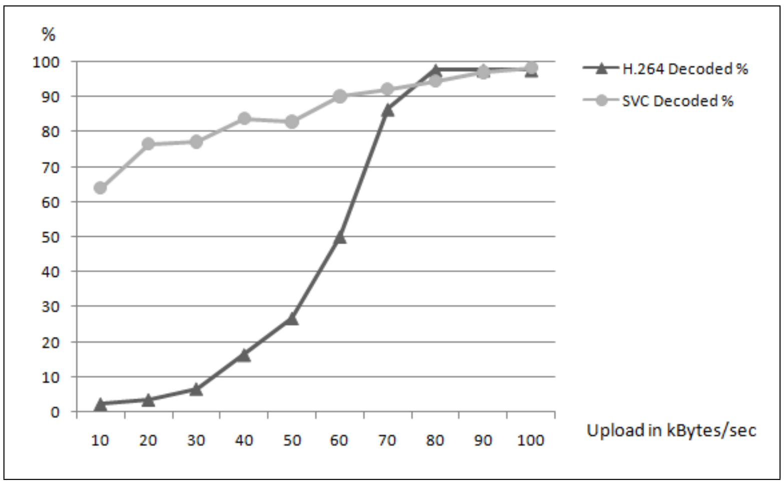


Figure 6.8: Percentage of decoded data (downloaded data = 100%)

However, as the upload capacity further rises, the differences between the H.264/AVC and the SVC stream diminish. The reason behind this development has two aspects . First, with a growing bandwidth the prioritization of video data within the SVC stream becomes less important. Concentrating on the basic parts of a video stream is mainly beneficial if only a small portion of the overall data is available. Second, if bandwidth becomes less of a problem, the overhead of SVC is getting a more important issue. At the highest upload capacities more bytes have to be downloaded for a SVC stream in order to achieve the best quality. This fact can also be seen in Figure 6.7 by the diverging download rates at an upload capacity of 70 kBytes/sec.

Chapter 7

Conclusion

This report discussed the up and downsides of Scalable Video Coding with particular attention to its application in peer-to-peer networks. In addition, the actual integration of scalable video into an existing peer-to-peer streaming software, namely Pulsar, was presented. As a conclusion it can be stated that on the one hand scalable video indeed has the potential to enhance the video streaming functionality of peer-to-peer networks. In particular flexibility in bit rate and error resilience can benefit from such a system. However, on the other hand increased coding complexity and considerable bit rate overhead have to be taken into account as well. Furthermore, due to its very recent approval the SVC standard has not yet found its way to broad application in publicly available systems. It remains to be seen if SVC can gain the same acceptance in video applications as its parent standard H.264/AVC is already enjoying.

7.1 Discussion

Though Pulsar is now able to handle scalable video streams, there is still room for further improvement. The most serious weak point of the system presented in the foregoing chapters, is clearly the dependency on the JSVM software. Especially three issues can be stated that have to be solved before Pulsar can offer scalable video on a broad scale.

First, JSVM is intended as reference software. Hence, its main focus lies on clearly representing the SVC standard rather than on performance issues. This fact challenged our demand to run the rewriter in real time. We managed to rewrite video sequences with a resolution of 400 x 224 in real time. Clearly there should be a high potential for significant performance improvements, given that the rewriting process itself is not a complex one.

Second, for the test runs so far a SVC bit stream was assumed to be given. Nevertheless, for actual application of SVC in Pulsar this issues needs to be reconsidered. One possible solution would be to keep the encoder out of Pulsar and further rely on external encoders like the one from JSVM. Due to the mentioned performance issues of JSVM this way is unlikely to provide a completely satisfying solution. Furthermore, the user interface of the JSVM encoder turns out to be too complicated for "mainstream" application. More promising but also obliged with a higher effort would be an alternative tailored specifically to Pulsar. As discussed in [71], a similar solution to the rewriter could be possible at the encoder side as well. This would include a rewriting process from H.264/AVC to SVC. Although special considerations concerning drift have to be regarded, rewriting to SVC is probably faster than completely encoding from an uncompressed video stream. Furthermore, this solution could be combined with already existing and established H.264/AVC encoders.

When further pursuing the idea of H.264/AVC to SVC rewriting, the system could come to a point where overhead due to additional scalable information can be completely avoided. This is possible if the regular H.264/AVC format is exclusively used for sending video data between peers. Only if a certain subset of layers needs to be extracted, the video stream is transformed to a SVC stream. In the SVC space specific enhancement layers are discarded and the remaining layers are rewritten back to the H.264/AVC format. In this way the SVC overhead only becomes locally noticeable at the peers and never affects the transmission bandwidth. The basic outline of this idea can be seen in 7.1.

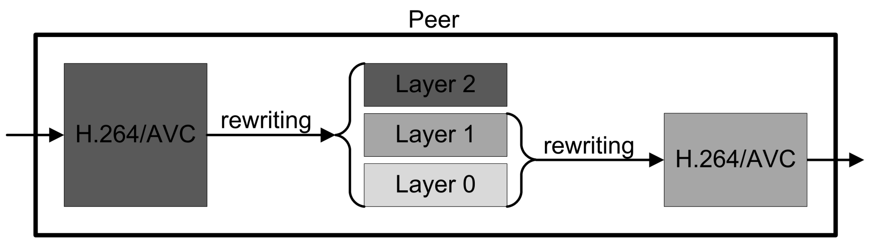


Figure 7.1: H.264/AVC to SVC rewriting

Third, license issues concerning the JSVM software have to be considered. Although the source code is freely available by today and no usage restrictions apply, this policy is not guaranteed to stay unchanged in the future.

7.2 Outlook

Following the discussion in the previous section, the foremost improvement of the system so far would be an independency from the JSVM reference software. This could solve most of the problems discussed in connection with the JSVM software, especially the performance issue. The process of rewriting itself does not involve any complex or time consuming tasks. Therefore, it is certainly possible to implement a rewriter, which is capable of rewriting SVC streams in real time with a far higher resolution than 400 x 224.

Before implementing a new rewriter, a decision concerning the programming language has to be made. One way would be to further rely on C++ for all fundamental video processing tasks, as it is the case today in JSVM or *FFmpeg*. This would only require the replacement of the external rewriter, while the basic architecture of the current system could be left untouched. Also parts of the JNI interface could be reused for this purpose. By contrast, a rewriter based on Java could be implemented as an integral part of Pulsar, which makes JNI interfaces between the rewriter and Pulsar obsolete.

Furthermore, also other scalability dimensions beside quality represent further possibilities for enhancement. Especially temporal scalability seems to offer interesting prospects, since its application does not require any modifications on the decoder side. Moreover, all our test sequences already included hierarchical B-frames. Consequently, modifications would be limited to Pulsar and its request and notifications policies for SVC streams in order to consider temporal layers in addition to quality layers.

As far as it concerns spatial scalability, combination with the concept of rewriting appears complicated. Due to the reasons mentioned in Section 5.2.4, spatial layers cannot be rewritten in an efficient way. An alternative would be to consider quality scalability a special case of spatial scalability by simply down scaling low quality layers for displaying. This could "hide" visual artifacts due to a poor video quality.

Besides extending the functionality of scalable video in Pulsar, also a deeper analysis of its application would be interesting. The evaluation part of this report (Section 6) can be continued to take a closer look at the actual advantages that scalable video offers in comparison to regular non-scalable video streams. Especially test scenarios with a diverse distribution of MGS layers among the peer would provide further insights into the performance of Pulsar using SVC. Besides the distribution of layers, as well varying packet sizes between the layers could influence test results. Furthermore, it would be interesting to examine the impacts of scalable video on the bandwidth distribution and bandwidth consumption of all peers. As well, issues in the field of incentive strategies specifically tailored at the purpose of scalable video offer questions for additional investigation.

On the protocol side of Pulsar new strategies can be tested that are specifically adapted for the requirements of scalable video. For example various incentive strategies can be compared in order to find the optimal assignment of *payback ratios* to scalable video layers. Furthermore, special request strategies could take into account the different importance of each scalable layer.

Therefore, it can be concluded that the application of scalable video in Pulsar opens up wide possibilities paired with further interesting challenges.

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