QUALITY IMPACT OF SCALABLE VIDEO CODING TUNNELING FOR MEDIA-AWARE CONTENT DELIVERY

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ABSTRACT

Today's omnipresent demand for access to multimedia content via diverse devices places new challenges on efficient content delivery. While the Scalable Video Coding (SVC) extension of Advanced Video Coding (AVC) has proven to be a useful tool for the advanced delivery of video content, it has not yet found major adoption in practice. This paper introduces the concept of SVC tunneling developed in the EU FP7 ALICANTE project, which attempts to provide device-independent access to media resources at reduced network load. For SVC tunneling, video transcoding is performed at the ingress/egress points of the network, which may impact the video quality. We show that the quality impact of these transcoding steps for a transcoding chain from MPEG-2 to SVC and back to MPEG-2 accumulates to a PSNR reduction of up to 2.1 dB for transcoding at fixed target bitrates. We also discuss research challenges and open issues in SVC tunneling.

Index Terms— Content-aware networking, scalable video coding, quality of service, SVC tunneling, transcoding, multimedia distribution

1. INTRODUCTION

The deployment of Scalable Video Coding (SVC) for content delivery enables bandwidth savings for multicast scenarios [1] and facilitates more robust video transport in content-aware networks [2]. Many devices, however, do not support scalable video formats and rely on non-scalable formats, e.g., MPEG-4 Advanced Video Coding (AVC), or even legacy formats like MPEG-2. One solution to the problem of deploying SVC streams in such an environment is the transcoding of video streams at the ingress and egress points of the network and the deployment of SVC tunneling within the network, thus enabling SVC content delivery and device-independent access.

The European FP7 Integrated Project "MediA Ecosystem Deployment Through Ubiquitous Content-Aware Network Environments" (ALICANTE) [3] follows this approach and proposes a novel concept towards the deployment of a new networked *Media Ecosystem*. The ALICANTE architecture introduces two novel virtual layers on top of the traditional network layer, i.e., a Content-Aware Network (CAN) layer for packet processing on top of the network layer and a Home-Box (HB) layer for the actual content adaptation, transcoding, and delivery. At the ingress and egress points of the network (i.e., the Home-Box), adaptation modules are deployed enabling device-independent access to the SVC-encoded content by providing X-to-SVC and SVC-to-X transcoding/rewriting functions, where X may denote MPEG-2, MPEG-4 Visual, MPEG-4 AVC, etc. This approach is especially important for scenarios in which the content is already encoded in MPEG-2 (e.g., DVD-Videos) and terminals only support legacy formats such as MPEG-2.

In this paper, we investigate the applicability of SVC tunneling for content delivery and the impact of repeated transcoding (i.e., X-to-SVC-to-X) on the video quality. Although the quality impacts of single transcoding steps are well known for a variety of video coding formats, the implications of two consecutive transcoding steps cannot be predicted from the individual steps.

Video transcoders in general provide several functions, ranging from conversion between video formats, over bitrate changes and frame rate adjustment to the enhancement of error resilience [4]. In this paper, we focus on format conversion which is also known as heterogeneous transcoding.

Throughout this paper, peak signal-to-noise ratio (PSNR) of the luminance component Y, known as Y-PSNR, is used as an objective metric of video quality.

The remainder of this paper is structured as follows. In Section 2 we introduce the ALICANTE architecture and identify scenarios for SVC tunneling. Section 3 focuses on SVC transcoding, addressing both transcoding to SVC and back from SVC to a target format. For both transcoding directions, we pay special attention to MPEG-2 as the source and target format, respectively. Section 3 also shows how the transcoding can be deployed for SVC tunneling and discusses the test setup for our objective quality measurements. The evaluation results for repeated transcoding are presented and discussed in Sections 4 and 5. Section 6 concludes the paper and provides an outlook on future work.

2. ALICANTE ARCHITECTURE

The ALICANTE architecture depicted in Fig. 1 proposes an advanced Media Ecosystem that delivers media content to different terminals at dynamically adaptable bitrates over a Quality of Service/Experience (QoS/QoE) managed network environment. Towards this goal, an SVC (layered-multicast) tunnel is developed in ALICANTE, inspired by IPv6 over IPv4 tunnels and the quality impact is investigated. Within the content-aware network, only scalable media resources, such as SVC, are delivered, allowing for in-network adaptation at Media-Aware Network Elements (MANEs). If the content at the server side originally has been encoded in a non-scalable legacy video format, e.g., MPEG-2, it is transcoded to SVC at the HB layer before delivery. Layered multicast is deployed at the CAN layer. When arriving at the client side, the scalable media resources can be transcoded to a format supported by the end user's terminal (e.g., again MPEG-2). The HB, which is a next generation interconnected home gateway, performs the transcoding. The HB sends the transcoded content via unicast through the home network towards its consumption at the terminal.

Video multicast (e.g., for IPTV services) to heterogeneous devices can be traditionally realized by two approaches; a third approach is provided through the ALICANTE architecture.

The first approach is to use a non-layered video format (such as AVC or MPEG-2) and send all content variants simultaneously. This approach is referred to as simulcast mode. Content variants may comprise different resolutions or different quality versions of a video. For simulcast mode, it is also possible to send the content in different video formats, thus enabling format independence for the receiver. The bandwidth requirement for delivering the content is the sum of bitrates for all variants being consumed by at least one user.

The second approach is to use SVC and to configure the SVC layers to fit these variants. In such a (receiver-driven) layered mode, the maximum required bandwidth is the bitstream up to the highest SVC layer being consumed by at least one user. Compared to AVC simulcast, this mode can reduce the required network capacity by around 18% [1]. The use of SVC at the network layer also empowers a content-aware network to perform efficient in-network adaptation, e.g., for QoS management.

ALICANTE introduces a third approach for multicast content delivery. The delivery is performed through an SVC tunnel, i.e., at the ingress point of the network the content is transcoded to SVC and it is transcoded back to the target format at the egress point of the network (i.e., Home-Box). This approach combines the format independence of the simulcast mode with the capabilities for bandwidth reduction and efficient in-network adaptation. However, this approach reduces the video quality due to its potentially two transcoding steps. This quality impact of the full SVC tunneling approach with both transcoding steps is investigated in Section 4. There are two variations of the SVC tunneling approach which require only one transcoding step. First, if the content is originally encoded in SVC, there is no need for transcoding at the server side. Second, if transcoding to SVC is performed at the server side but the terminals support SVC, the second transcoding step can be omitted.

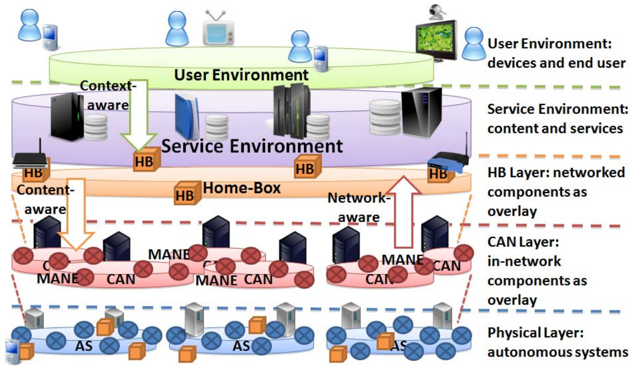

Fig. 1. ALICANTE concept and system architecture [5].

For the evaluations in this paper, we assume that both content provider and end user require the same video format (i.e., MPEG-2). The ALICANTE architecture is more general in this respect and allows for different video formats at the sender and receiver sides.

SVC tunneling also enables advanced QoS/QoE management in content-aware networks. MANEs distributed across the network can perform in-network adaptation [2] on the SVC bitstream in order to adjust to changing network conditions.

3. SVC TRANSCODING

SVC follows a layered coding scheme comprising a base layer and one or more enhancement layers providing scalability along various dimensions [6]. Three basic scalable coding modes are supported, namely spatial scalability, temporal scalability, and signal-to-noise ratio (SNR) scalability, which can be combined into a single coded bitstream.

When it comes to compression, SVC with dyadic spatial scalability requires about 10% more bitrate than single layer AVC for the same video quality [7]. But compared to MPEG-2, which requires approx. 170% more bitrate than AVC [8], SVC still provides a bitrate reduction of about 59% (calculated from *1-(1+0.1)/(1+1.7)*) w.r.t. MPEG-2.

3.1. Transcoding to SVC

The simplest but slowest architecture of transcoding between two video formats is accomplished by fully decoding the video and then re-encoding the pixels into the target format, which is known as pixel domain transcoding (PDT), cascaded transcoding, or full transcoding [4][9]. It usually provides the best quality and is used as a reference for more advanced transcoding mechanisms. Since the video has to be fully decoded and fully re-encoded, this architecture is rather slow and computationally expensive. The computational complexity can be reduced by using information from the coded source video to create the target video. For example, the motion vectors can be extracted and mapped to the target coding. Advanced transcoding is usually performed in the transform domain. The transform coefficients are extracted from the encoded source video and converted to the transform coefficients of the desired format. This technique is called transform domain transcoding (TDT) [4]. TDT is considerably faster than PDT but usually introduces higher quality losses [10]. However, each format has its own way of encoding videos, leading to specialized transcoders for each format conversion.

A special case of transcoding is bitstream rewriting, which converts the video from one format to another without any quality losses. Bitstream rewriting is only possible if both video formats use the same bitstream syntax and coding techniques, which is the case for AVC and SVC [11]-[14]. Note that lossless bitstream rewriting may still increase the bitrate if the target format has a lower coding efficiency, as it is the case for AVC-to-SVC rewriting.

While a variety of transform domain transcoders from different formats to AVC exist (e.g., from MPEG-2 [15], [16]), for SVC only transcoding and rewriting techniques from AVC as the source format have been researched so far [11]. To the best of our knowledge, no MPEG-2-to-SVC TDT has been addressed in any research so far. In order to transcode from MPEG-2 to SVC, either PDT or cascaded TDTs can be deployed. In the first case, the video is decoded from MPEG-2 and then re-encoded to SVC. In the latter case, a fast MPEG-2-to-AVC transform domain transcoder and a fast AVC-to-SVC rewriter are cascaded.

In this paper, we focus on MPEG-2-to-SVC PDT rather than cascaded TDTs. The PDT architecture is more generic and allows for transcoding from virtually any source format to SVC by simply plugging in the appropriate decoder. PDT also establishes a proper baseline for MPEG-2-to-SVC transcoding.

3.2. Transcoding from SVC

The SVC base layer is backward-compatible to AVC. The full SVC bitstream can be converted to AVC through lossless bitstream rewriting [12]-[14]. To the best of our knowledge, transcoding techniques from SVC have only been researched for AVC as target format. For transcoding SVC to other target formats, such as MPEG-2, two architectures are possible, similar to the X-to-SVC transcoding architectures described above. The first architecture uses PDT, fully decoding the SVC bitstream and re-encoding it to the target format. The second architecture comprises cascaded TDTs, i.e., SVC-to-AVC bitstream rewriting followed by fast TDT from AVC to the target format (e.g., AVC-to-MPEG-2 TDT [17][18]). Again, we have chosen the more general PDT architecture for SVC-to-MPEG-2 transcoding in order to establish a proper baseline for future research.

3.3. Repeated transcoding and test setup

For multicast scenarios in which the content has been originally encoded to a non-scalable legacy format like MPEG-2 (e.g., DVD-Videos) and also the user terminals require MPEG-2, an SVC tunnel for content delivery, as proposed by ALICANTE, could be deployed in order to enable QoS/QoE management at the network and possibly to reduce network load. However, such an SVC tunnel requires two transcoding operations, first MPEG-2-to-SVC transcoding at the server side and second SVC-to-MPEG-2 transcoding at the client side (i.e., the HB). Since the PSNR is computed from the mean squared error (MSE), which contains quadratic terms, it is not possible to estimate the quality impact of this repeated transcoding by just accumulating the PSNR values of each transcoding run.

In order to evaluate the quality impact of this repeated transcoding, we performed the transcoding operations on two standard test sequences, *Foreman* and *Mobile* (CIF at 30 fps, 300 frames).

In the first step, each sequence was encoded from raw YUV to MPEG-2 using *FFmpeg* version SVN-r25599 [19] and its *mpeg2video* codec. In the second step, the output stream was then transcoded by decoding it using the *GPL MPEG-1/2 DirectShow Decoder Filter* Version 0.1.2 [20] and encoding it to SVC using the *MainConcept SVC/AVC/H.264 Video Encoder* Version 1.0.0.236699 [21] DirectShow filter. The SVC bitstream has three layers with the following encoder configuration. The base layer is specified at QCIF at 30 fps and 15% of the target bitrate of the highest layer and the first enhancement layer with CIF at 30 fps and 30% of the target bitrate of the highest layer. The second enhancement layer (i.e., highest layer) is specified with CIF at 30 fps and 100% of the video target bitrate.

The bitstream was transcoded back to MPEG-2 in the final step by decoding it using the *MainConcept SVC/AVC/H.264 Video Decoder* Version 1.0.0.236699 DirectShow filter and encoding it using *FFmpeg* and the *mpeg2video* codec.

The encoding of each sequence was performed at several target bitrates. At all three steps, encoding was performed at fixed target bitrates, i.e., the video was encoded to MPEG-2 at the same target bitrate as it was transcoded to SVC and transcoded back to MPEG-2. For example, if the video was initially encoded to MPEG-2 at a target bitrate of 2,000 kbps, it was transcoded to SVC at 2,000 kbps target bitrate and transcoded back to MPEG-2 at this same target bitrate.

The PSNR was always measured against the original raw YUV video. The differences in PSNR and bitrates between two steps were calculated as the improved Bjontegaard Delta (BD) [22]. The BD measures the average distance between two rate-distortion (RD) curves along the PSNR and bitrate axes.

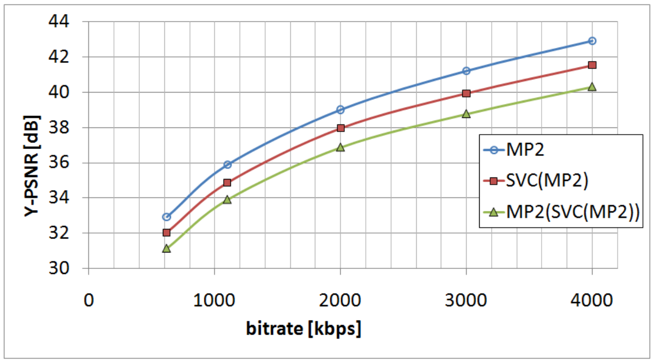

Fig. 2. Y-PSNR for repeated transcoding of *Foreman* sequence.

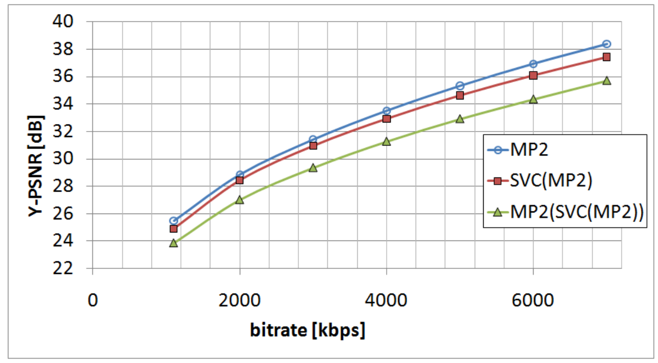

Fig. 3. Y-PSNR for repeated transcoding of *Mobile* sequence.

4. EXPERIMENTAL RESULTS

The RD curves of the repeated transcoding are shown in Fig. 2 for the *Foreman* sequence and in Fig. 3 for the *Mobile* sequence, each for the extraction of all SVC enhancement layers. The RD curve after MPEG-2 encoding is labeled *MP2*, the RD curve after MPEG-2-to-SVC PDT is labeled *SVC(MP2)*, and the RD curve for the final SVC-to-MPEG-2 PDT is labeled *MP2(SVC(MP2))*.

For the *Foreman* sequence, both transcoding steps (MPEG-2-to-SVC and SVC-to-MPEG-2) have nearly the same impact on the video quality. Conversely, the *Mobile* sequence indicates only slight quality losses for MPEG-2-to-SVC transcoding (BD-PSNR of 0.5 dB between first and second curve) compared to the impact of SVC-to-MPEG-2 transcoding (BD-PSNR of 1.5 dB between second and third curve).

The individual and average results are represented as the BD of the PSNR and bitrate in Table 1. On average, the repeated transcoding results in a total PSNR drop of 2.1 dB or conversely a bitrate increase of 43% in order to compensate for the PSNR drop.

Based on these results, the bandwidth requirements for a multicast streaming architecture can be estimated for three scenarios as shown in Fig. 4. The MPEG-2 simulcast mode, in which 3 quality versions of the content (as specified in Section 3.3) are streamed, requires 145% of the bitrate of the original MPEG-2 video. The simulcast mode is depicted as a baseline in Fig. 4, labeled *Scenario 1*. The other two scenarios considered in the figure are the full SVC tunneling mode, labeled *Scenario 2*, with MPEG-2-to-SVC and SVC-to-MPEG-2 transcoding, and, as *Scenario 3*, SVC multicast streaming with only MPEG-2-to-SVC transcoding at the ingress point of the network. SVC content delivery in both latter scenarios reduces the bandwidth requirements at the core network by approx. 31% w.r.t. the simulcast mode, at the expense of degraded video quality (-2.1 dB for *Scenario 2* and -0.8 dB for *Scenario 3*). *Scenario 3* assumes that the end user terminals also support SVC and thus no SVC-to-MPEG-2 transcoding is required.

Note that the content delivery in all three scenarios is based on the same video at the sender. In order to obtain equal video quality results at the end user terminals for MPEG-2 simulcast mode and SVC layered multicast, the bitrate of the MPEG-2 video for simulcast mode (*Scenario 1*) could be throttled according to Table 1. However, this would imply deliberately sending suboptimal video quality to simulcast mode users, which only make sense if the available network bandwidth is scarce.

5. DISCUSSION OF EXPERIMENTAL RESULTS

While the SVC tunnel architecture with the presented test setup provides a moderate reduction of bandwidth compared to the higher coding efficiency of SVC w.r.t. MPEG-2, it should be noted that the repeated transcoding in this test setup has used fixed target bitrates for all three operations in order to establish a valuable baseline which shall also enable future research.

The current architecture can be improved for both transcoding steps. In the MPEG-2-to-SVC transcoding step, the target bitrate for SVC could be reduced according to SVC's higher coding efficiency over MPEG-2. On average, it should be possible to reduce the SVC bitrate by 59% (cf. Section 3) while maintaining BD-PSNR results similar to fixed target bitrates. However, as coding efficiency may vary depending on the content, the selection of appropriate SVC target bitrates remains a research challenge. The naïve solution is to statically reduce the bitrate for MPEG-2-to-SVC transcoding by about 59%. The theoretically ideal solution would be to encode the raw video to SVC and measure the ratio of MPEG-2 bitrate vs. SVC bitrate in order to determine the appropriate bitrate reduction for that specific content. But this solution is not applicable for scenarios in which the content is only available in MPEG-2 (e.g., DVD-Videos). A more practical solution would be to steer the transcoding through the quantization parameter (QP) instead of target bitrate.

Furthermore, in the SVC-to-MPEG-2 transcoding step, the final video quality could be additionally improved by artificially bloating the bitrate of the MPEG-2 bitstream. The ALICANTE architecture uses Home-Boxes at the client's premises to perform this transcoding step. Supposing that the client's home network is over-provisioned, even a small increase of quality can outweigh the bitrate increase in terms of end user experience. The actual amount of bitrate

Table 1. Bjontegaard Delta of RD curves for repeated transcoding.

Foreman sequence:	BD-PSNR	BD-bitrate
1st to 2nd curve (MPEG-2→SVC)	-1.1 dB	23%
2nd to 3rd curve (back to MPEG-2)	-1.0 dB	23%
1st to 3rd (MPEG-2→SVC→MPEG-2)	**-2.1 dB**	**51%**
Mobile sequence:	BD-PSNR	BD-bitrate
1st to 2nd curve (MPEG-2→SVC)	-0.5 dB	8%
2nd to 3rd curve (back to MPEG-2)	-1.5 dB	26%
1st to 3rd (MPEG-2→SVC→MPEG-2)	**-2.1 dB**	**36%**
Average:	BD-PSNR	BD-bitrate
1st to 2nd curve (MPEG-2→SVC)	-0.8 dB	15%
2nd to 3rd curve (back to MPEG-2)	-1.3 dB	25%
1st to 3rd (MPEG-2→SVC→MPEG-2)	**-2.1 dB**	**43%**

bloating depends on several factors, such as the capabilities of the transcoding machine (i.e., the Home-Box), spare home network capacity, and the (decoding) capabilities of the client terminal. Especially in cases where the home network capacity is the crucial factor for bloating the MPEG-2 bitstream, it makes sense to steer the transcoding through target bitrate rather than QP. The quality gain of bitrate bloating for SVC-to-MPEG-2 transcoding is subject to future work.

In addition to the architectural enhancements, the particular configuration of the transcoding setup implemented in this paper could be improved in several aspects, such as the choice of SVC layer configuration or the deployment of other transcoding components.

The two transcoding steps for SVC tunneling result in a PSNR drop of 2.1 dB. Based on the proposed mapping of PSNR to the Mean Opinion Score (MOS) in [23], the perceptibility of the PSNR drop, represented as Differential MOS (DMOS) on the Absolute Category Rating (ACR) scale (from 1 to 5) [24], can be roughly estimated between 4.83 in the best case and 4.63 in the worst case according to Equation (1).

$$DV(PVS)=V(PVS)-V(REF)+5 \qquad (1)$$

DV(PVS) is the calculated differential viewer score and *V(PVS)* and *V(REF)* are the individual viewer scores of the processed video sequence and reference respectively. This equation is also applicable to the MOS because the function for *DV(PVS)* and the arithmetic mean of the MOS are commutative. Note that this is only a first estimate to provide an impression of the perceptibility of the quality reduction. Subjective tests for the evaluation of the perceived quality impact will be performed in future work.

The research presented in this paper focuses on quality impact of repeated transcoding, leaving aside any delay aspects, real-time constraints, and processing performance. Delay may not matter for non-real-time media services, like pre-recorded TV broadcasts or Video on Demand services, if the content can be transcoded and prepared in advance.

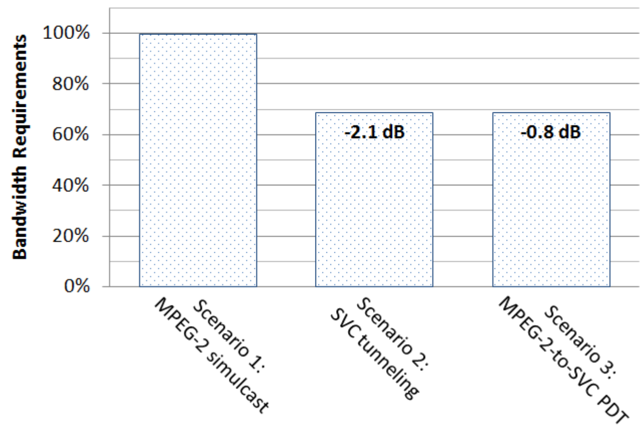

Fig. 4. Estimated bandwidth requirements at the core network and corresponding quality degradation for multicast streaming.

On the other hand, especially for live content low transcoding delay and high processing performance of the transcoding equipment are crucial.

Besides the objective video quality measurements conducted in this paper, further subjective quality tests need to be performed. The repeated transcoding from MPEG-2 to SVC and back to MPEG-2 might have some visual side effects on the video quality that cannot be determined from PSNR results alone.

6. CONCLUSIONS AND FUTURE WORK

In this paper we have presented the concept of SVC tunneling for multicast content delivery. The proposed architecture may require video transcoding from and to non-scalable legacy video formats, such as MPEG-2, at the ingress and egress points of the network. We have investigated the applicable transcoding methods and have evaluated the quality impact of the repeated transcoding at network borders. This transcoding chain results in a total PSNR decrease of 2.1 dB, with around 1/3 of the quality impact attributed to the initial MPEG-2-to-SVC transcoding step. A bitrate increase of 43% is required to compensate the quality loss, which is still less than the necessary bandwidth for MPEG-2 simulcast-based streaming.

Our measurements are expected to serve as guidelines for the estimation of quality reduction and its possible compensation in SVC tunneling scenarios.

In this paper, test results for two test sequences have been presented. A wider variety of test content, also comprising (ultra) high-definition resolutions, will be considered in future work.

The presented research focuses on MPEG-2 as the source and target format in order to support legacy devices. Future work will investigate further coding formats, e.g., MPEG-4 AVC, as newer end user devices already support MPEG-4 AVC.

The goals of SVC tunneling for content delivery are the reduction of network load through cumulative layered multicast and the provisioning of QoS management in content-aware networks. Within the ALICANTE project, the exploitation of content-aware networking for SVC tunneling is explored, ranging from in-network adaptation to intelligent routing mechanisms. Future work will elaborate the evaluation of possible savings in bandwidth for SVC tunneling and the corresponding impact on video quality, investigate timing constraints for transcoding and develop a signaling framework for deployment in ALICANTE's advanced Media Ecosystem.

7. ACKNOWLEDGMENT

This work was supported in part by the EC in the context of the ALICANTE project (FP7-ICT-248652).

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