Quality Aware, Adaptive, 3D Media Distribution over P2P Architectures

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***Abstract*— Recent advances in video distribution over the Internet have inevitably led to the need for accompanying the video related value-added services with the means for maintaining integrity and quality of distributed media to optimize Quality of Experience (QoE). Current systems cover the aspects of maintaining the quality of 2D (only) media by conducting user requirements surveys and 2D QoE assessments. This paper presents the work performed in the EU FP7 SARACEN research project on personalized 3D media streaming over P2P architectures, together with evaluation tests and results as regards scalable and adaptive coding for 3D video streams.**

Keywords—3D video, media streaming, P2P, QoE

I. INTRODUCTION

Since the dawning of the Internet based video distribution era, that came to challenge the traditional TV broadcast, the evolution in Internet technologies, as well as the particular techniques for ensuring high quality, high demand video distribution has driven the video encoding, distribution and delivery technologies through several stages of evolution. The result has been the substitution of the one-to-many, linear, low resolution (over the air or cable) video broadcasting, by a many-to-many, user-centric, personalized model, where the end-user is able to access a large pool of live or on demand programs, videos and rich-media, semantically enhanced, through any capable video terminal, irrespective of the screen size, processing power, or type of network connection. In order to live up to increased expectations that such a diverse environment of network technologies, devices and service characteristics introduce, a series of techniques as regards both video encoding as well as distribution have been proposed.

The need to address both scalability and multi-source contribution of the delivered stream, together with the inability of end to end IP Multicast support across domains over the Internet, has led to the adoption of Application Layer Multicast (ALM) tree distributions over multiple Autonomous Systems (ASs), which are currently responsible for the distribution of content by many content providers. This way, they avoid neighborhood congestion in the server's network and provide a wider geographical range for the distribution. Going one step forward and trying to take advantage of the increased network capabilities, terminal processing power and storage capacity, the P2P video distribution model has started to gain ground over the traditional client-server based approach. The organization of the end client systems in an overlay mesh network of peers, where each peer acts both as server (that provides service to other peers) and as client (which consumes resources from other peers), apart from providing the base for an alternative model for video distribution, harnessing the power of peripheral networks and domains, it constitutes a shift from classical "monopolist" linear TV distribution towards non-linear, on-demand, anytime, anywhere, cross device audio-visual consumption.

Many projects and platforms have deployed P2P technologies (at a different level of success) for the distribution of streaming media: Babelgum, Coolstreaming, Cybersky-TV, Feidian, Livestation, PeerCast, Joost, RealTime.com and RawFlow ICD. Within this list, we can find projects that have addressed the issue of deploying social networking and trying to provide personalised services, while attempting to address Quality of Service (QoS) issues through a variety of approaches. However, a traditional approach was followed in all cases, without

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research or deployment of novel techniques for 2D/3D encoding and transporting of information, while no significant results as regards standardisation on personalisation or user profile issues have been recorded.

In parallel, trying to address the lack of guarantees in quality and network parameters, synonymous to Internet, adaptive behavior over the transmitted stream has been recently adopted, taking advantage of the stateless nature of HTTP as well as the ability of multiple rate coding of streams. As a result, several techniques offering dynamic, adaptive media streaming over HTTP have been proposed [7], [8], and [9]. Going another step further and substituting the idea of multiple coded versions of the same media file/stream, state of the art research includes Scalable Video Coding (SVC) and Multi-view Coding (MVC), extensions of the H.264/MPEG-4 Advanced Video Coding (AVC) standard [1], that respectively support the encoding in several hierarchical levels of quality and the encoding of several views. Furthermore, the need for covering the requirements of next generation Ultra High Definition video, has led to the introduction of High Efficiency Video Coding (HEVC), currently under definition.

The rest of the paper presents the challenges in 3D media streaming in Section II, the approaches taken in the SARACEN project as regards the video distribution of streams over P2P architectures with respect to QoS and QoE, in Section III, and, in Section IV, the results of the evaluation performed in the context of the project.

II. CHALLENGES IN ADAPTIVE AND SCALABLE 3D MEDIA STREAMING

A. *The standard issues*

This Section states the (extra) challenges for the introduction of 3D media in P2P video streaming. It also considers alternatives that should be examined. Trying to combine the state-of-the-art developments in media streaming with 3D video, with the concept of SVC video distribution over a P2P network creates a set of new and exciting challenges. Some of these challenges were tackled and successfully solved in the SARACEN project, and will be presented later in the paper [3].

Foremost, it is worth remembering that in most cases a 3D video consists of a number of separate video streams, one for each view (assuming that neither inter-view coding nor depth maps are applied). Consumer systems available today offer stereoscopic 3D with two views. Flexibility can be added to the system by delivering these views separately, but it still has to take into account the approximately double bandwidth requirement when compared to a 2D stream.

However, it is not an absolute requirement to provide equal quality for each of the views. Human Visual System (HVS) have an astonishing ability of masking low quality image delivered to one eye, if quality delivered to the second eye is high [4]. Combined with SVC, this HVS ability opens a wide scope of modes in which 3D content can be delivered if suitable bandwidth is not available.

Another concern is related to fluctuating available bandwidth in time, as it may prevent the system to support 3D forcing it to fall back to 2D mode of playback. The question that needs to be tackled is the following: "what will provide better overall QoE for the user: low quality 3D or high quality 2D? Furthermore, should we switch back to 3D once the available bandwidth goes up? ". For the presented research we have focused on a case of stereoscopic video with two views since even though the architecture of the SARACEN system is scalable and ready for the introduction of multi-view content, there are no consumer-grade, high quality solutions for multi-view playback.

B. *The (Extra) Challenges*

One of the main objectives of nowadays' video systems is maintaining integrity and quality of media to optimize QoE in collaborative media creation and delivery scenarios (sharing, storage, retrieval, fusion capabilities). Current systems usually already cover the aspects of maintaining the quality of 2D (only) media by conducting user requirements surveys and 2D QoE assessments. Nevertheless, the new challenge is to work on QoE of not only 2D, but also 3D contents [11], as well as to ensure maintainability of high 3D quality while utilizing novel, P2P delivery methods. These challenges are discussed in more detailed below.

Nowadays, adaptive streaming with congestion control using SVC becomes more and more available. Unfortunately, in state-of-the-art systems, the 3D content is usually not adapted to user preferences, user environment and capabilities of a user's device. Another issue is congestion control. Current P2P streaming architectures are capable of providing congestion control. Nevertheless, these P2P architectures are usually not capable of transmitting 3D streams in a congestion-resilient way, as they have not been designed to meet the particular needs for 3D video streaming. Yet another important issue is QoE fairness for multiple users with different QoE requirements. In 3DTV, new (if compared to 2DTV) distortions are introduced. The first is the lack of the 3D effect, and the second is asymmetric quality i.e., different quality for each of the stereoscopic views resulting in different quality received by each eye. Unfortunately, nowadays, the QoE of the 3D content delivered with P2P architecture is rarely measured and monitored. Consequently, potential sources of impairments usually remain unidentified.

Finally, today it is becoming obligatory to provide standardized user profiling, and to personalize systems focusing on media content. Nevertheless, current P2P protocols are rarely aware of the user profile concerning the 3D aspects. In summary, there are research goals in 3DTV, focused more around end-user QoE, moving away from traditional, network oriented approaches that evolve mostly around QoS, and shifting towards the actual experience of the user. The primary focus should be the scalable and personalized streaming of 3D content in P2P overlays, which will allow to progress beyond the challenges described above. The expected result is the creation of QoE models (through conduction of psycho-physical tests) that will result in high QoE of the media delivered via a P2P platform.

III. THE NOVELTY OF THE SARACEN PROJECT APPROACH

The rapid progress in hardware/software media technologies has changed the role of individuals from passive content consumers to active content creator/producers. It is clear that in a few years everyone will be multimedia content producer (by publishing digital pictures, video recordings, remote e-health services, home surveillance, etc.), multimedia content mediator (by storing/forwarding streaming content) and multimedia content consumer (digital television, video on demand, mobile broadcasting, 3D and alike).

Within such environment, collaborative, social /context aware and scalable media distribution is required for:

- Maintaining the integrity and quality of delivered multimedia content.
- Optimizing the quality of experience in a way of delivering truly personalized high Quality of Experience (QoE) media streaming services.
- Adapting and enriching the quality of media across the whole distribution chain.
- Collaborative, personalized and contextual media streaming tools for P2P unstructured and distributed topologies for 2D and 3D content.

The main goal of the SARACEN project that concluded it research work in April 2013, was to research and develop a platform, over which, high quality multimedia streams could be supported through innovative techniques for media encoding and for media distribution. To achieve this, the project has focused on the use of scalable media coding techniques, combined with P2P architectures. SARACEN has tried to merge the research efforts in both scalable coded media and P2P Streaming in order to deliver high quality streaming media, and even go one step further, by introducing social networking in the media production and media distribution scheme, making it content-aware, and adapted to the personal needs and requirements of the end-users. Finally, all the above were addressed having in mind the particularities and needs of 3D media streaming, with respect to QoE support over heterogeneous access networks in a networked optimized framework.

A. *P2P architecture for scalable and adaptive video streaming*

The P2P distribution network architecture in SARACEN (Fig. 1) considers end-user nodes (Terminals) and Serving Platforms. The end-user nodes are distributed Peers (with P2P capabilities) that produce, consume and share contents, offering their resources (bandwidth, processing power, storing capacity) to the other end-user nodes.

The Serving Platforms are centralized service nodes providing control (Tracker), content treatment and distribution (transcoders and Media Servers), publishing and searching features, as well as Social Networking interaction tools and facilities.

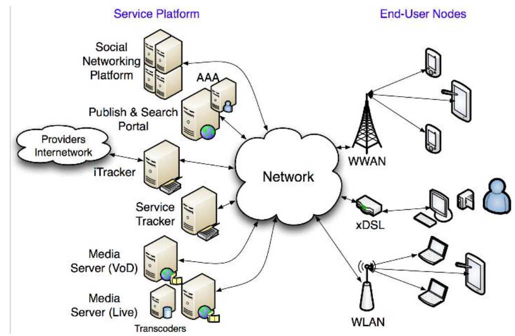

Fig. 1. Distribution Network Architecture using P2P in SARACEN

Peers and service nodes use multiple protocols to communicate. For content distribution, a specific suite of P2P Streaming Protocols is used for resource discovery, signaling, streaming control, streaming transport, etc. All information exchanged between the Tracker and the peers, and between the peers is encoded in XML bodies conveyed in HTTP. For content generation, the live media can be captured using different devices (e.g., video cameras, smartphones, files, etc.) and encoded into layered video like MPEG4 H.264/SVC [1] or MDC (Multiple Description Coding) [2].

The P2P distribution network architecture requires peers able to communicate with a tracker in order to participate in a particular swarm. This centralized tracker service is used for peer bootstrapping and for content registration and location. Content Media Presentation Description (MPD) files for each content, include reference to swarm identifier and the corresponding tracker, allowing the association of content location information to the swarm of peers streaming the content.

The process used for streaming distribution relies on a segment transfer scheme whereby the original content is re-encoded using adaptive or scalable techniques and then chopped into small video segments corresponding to a short play-out duration (in the order of a few seconds). With this method the system can support the following streaming mechanisms:

- adaptive – alternate versions of the content with different qualities and bitrates;
- scalable description levels – multiple additive descriptions of the content (i.e., addition of descriptions refine the quality of the video);
- scalable layered levels – nested dependent layers corresponding to several hierarchical levels of quality,

i.e., higher enhancement layers refine the quality of the video of lower layers.

- scalable multi views – views correspond to 2D and to stereoscopic 3D videos, with several hierarchical levels of quality.

These streaming distribution techniques support dynamic variations in video streaming quality while ensuring support for a plethora of end-user devices and network connections.

The function entities related to P2P Streaming Protocol (PPSP) are the Client Media Player, the service Portal, the Service Tracker and Peers. The Service Tracker is a logical entity that maintains the lists of PPSP active peers storing and exchanging segments for a specific content. The tracker answers queries from peers, collects information on the activity of peers, and stores the status of peers to help in the selection of appropriate candidate peers for a requesting peer. The service Portal is a logical entity typically used for client enrollment and content information publishing, searching and retrieval. The Client Media Player provides a direct interface to the end user at the client device, and includes the functions to select, request, decode and render contents. In PPSP the Client Media Player interfaces with the peer using request and response standard formats for HTTP Request and Response messages [10].

B. 3D Video support

In order to support 3D video, the development of SARACEN featured a VLC player with two important 3D video support plugins. The plugins for 3D streaming and decoding are: "input" and "ksvc". The first plugin reads segments and prepares them for decoding. The second plugin decodes each frame of the stream. In the final complete prototype, the plugins for 3D video have been integrated into the player.

In order to ensure scalability, the plugins provide support not only for 3D H.264, but also for 3D SVC video. Furthermore, quality scaling is complemented with an implementation of a special function, giving the ability to intelligently select between 2D and 3D.

In order to be able to support adaptive video streaming, SVC was adopted in SARACEN, in order to take advantage of the main aim of developing SVC technology: low-complexity video adaptation, retaining comparable compression efficiency and decoding complexity to those of conventional (non-scalable) video coding systems. SVC creates specific situation where a particular layer is either available or not. Therefore the (only) visible effects are compression artifacts. Furthermore, the availability of layers is dynamic, thus changes over a time.

When streaming scalable media over P2P, the system tries to maximize the steam quality by requesting the maximum number of segment layers. If the available bandwidth is too narrow, no layer segment would arrive before play-out deadline and the display of the sequence may freeze (unless there is still enough data in the buffers). Therefore the logic for requesting segments is an important system feature. In the case of 2D sequences, this is somewhat easier than for 3D, as without segments containing a layer [0,i] it is impossible to use information from the layer i+1. As a consequence, layers are requested in an order making it possible to obtain the best possible quality. Such methodology is not sufficient for 3D sequences, since different strategies are possible due to the multi-view characteristics of the content. For example, having already layer 0 from the left view and layers 0 and 1 from the right view, the system could download and use layer 1 from the left view or layer 2 from the right view. The sequences obtained would be different.

All this requires a more dynamic switching between the layers. It is not clear whether in temporary improvements of the quality of transmission, it is better to temporarily increase the number of display layers, or not, because it is better not let the user perceive frequent quality jumps. Therefore, there is a motivation to examine the different patterns of response to switching levels of quality.

IV. EVALUATION THROUGH EXPERIMENTS

SVC 3D signal contains different views encoded with different quality levels. The main target of a delivery system is to provide the best possible quality for the given conditions. The main two questions are:

- What is the optimal order for downloading layers/views?
- How annoying is the quality fluctuation?

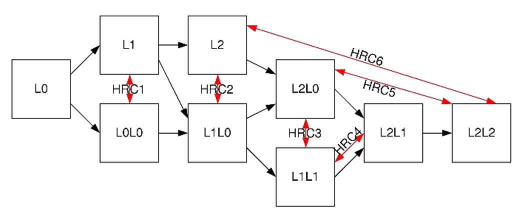

Fig. 2. Layer and views download order. Each arrow marks possible decision. The read arrows marks HRCes.

Tto answer both questions two subjective experiments, were performed. Full details on the experiments, including processing of sequences, have been reported in SARACEN Deliverable D3.5 [5] and SARACEN Deliverable D7.3 [6]. The first question was answered by a double stimulus subjective experiment based on NAMA3DS1-COSPAD1: subjective video quality assessment database on coding conditions introducing freely available high quality 3D stereoscopic sequences [12]. The downloading order of Hypothetical Reference Circuits (HRCes) is presented in Fig. 2. The chosen pairs compare different aspects of the system.

- HRC1 result reveals a download strategy after left view layer 0 is downloaded.

- HRC2 result reveals a download strategy after left view layer 1 is downloaded.
- HRC3 result reveals a download strategy after left view layer 1 and right view layer 2 are downloaded.
- HRC4 helps is specifying if a small differences can be visible by subjects. Moreover, thanks to the quality scale it is possible to estimate if the differences are visible and also their strength.
- HRC5 helps to detect irrelevant subjects since in this case the quality difference is obvious. Moreover, thanks to the quality scale it is possible to estimate the quality difference strength.
- HRC6 is simple 3D versus 2D preference test. If a user choose 3D streaming scenario depending on the bandwidth it is possible choose between sending 2D signal but with better quality or 3D with worst. If a higher bandwidth is available the question showing better 2D or worst 3D changes to 3D strategy and a question "what is quality difference?" Such different strategy evaluation is the main reason for such HRCs.

According to pair comparison methodology, each HRCs appears in two or four different versions. If both views have the same quality, HRCs have two versions with different sequence order. For example HRC1 is shown as L1 with L0L0 and L0L0 with L1 comparison. If the quality of different views is different, then four pairs are used. For example HRC2 has such pairs: L2 with L1L0, L2 with L0L1, and L1L0 with L2 and L0L1 with L2. Such methodology makes possible to remove or add to the random noise any order influence coming.

TABLE I. HRC FOR THE CHANGE QUALITY EXPERIMENT. EACH COLUMN DESCRIBES QUALITY OF THE CORRESPONDING TIME INTERVAL.

HRC	0-2.56	2.56-5.12	5.12-7.68	7.68-10.24	10.24-12.80
1	2DBL	2DBL	2DBL	2DBL	2DBL
2	3DBL	3DBL	3DBL	3DBL	3DBL
3	2DBL	3DBL	3DBL	2DBL	2DBL
4	3DBL	3DEL	3DEL	3DBL	3DBL
5	3DBL	2DBL	2DBL	2DBL	2DBL
6	3DEL	3DBL	3DBL	3DBL	3DBL
7	3DBL	2DBL	2DBL	2DBL	3DBL
8	3DEL	3DBL	3DBL	3DBL	3DEL
9	3DBL	2DBL	2DBL	3DBL	3DBL
10	3DEL	3DBL	3DBL	3DEL	3DEL
11	3DBL	2DBL	3DBL	2DBL	3DBL
12	3DEL	3DBL	3DEL	3DBL	3DEL
13	3DBL	2DBL	3DBL	3DBL	3DBL
14	3DEL	3DBL	3DEL	3DEL	3DEL
15	3DEL	3DEL	3DEL	3DEL	3DEL
16	2DEL	2DEL	2DEL	2DEL	2DEL

The first experiment showed the correct downloading order and the quality difference for small quality changes. Nevertheless, the quality fluctuation can be annoying even if it is not easily visible. Therefore, the next test was focused on the quality change. Since a pattern of quality change is unique, an Absolute Category Rating (ACR) subjective experiment was used. The considered scenarios are shown in Table 1.

As it was mentioned before, it is not clear whether in the situation of temporary improvement of the quality of transmission, if it is better to temporarily increase the number of display layers, or not, because it is better not let the user perceive frequent quality jumps. Therefore, different patterns of response to switching levels of quality were examined. The goal of the test was to compare the qualities of some of the sixteen possible sequences, each of the sequences consisting of five segments, each having 64 frames (2.56 seconds if frame rate is 25). HRC were selected in such a way that the different downloading strategies available for the SARACEN system were addressed. Table 1 shows these details. 2D means one view copied to another while 3D means two independent views. BL means SVC Base Layer (corresponding to L0 from the previous SARACEN experiment) while EL means SVC Enhancement Layer (corresponding to L2 from the previous SARACEN experiment). Segment play-out order is from left to right.

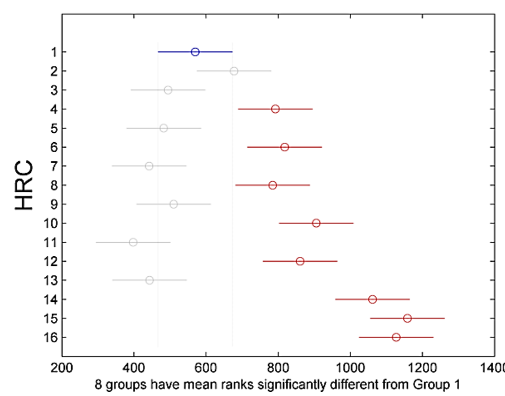

Fig. 3. Kruskal-Wallis test results for HRCes. The last two HRCes are used as a reference.

An important evaluation conclusion for the system administration is that changing between 2D and 3D creates poor quality. As such, it should be avoided. More detail HRC analysis is shown in Fig. 3. HRC 15 and 16 are used as reference and control points since both have the extended layer for 2D and 3D respectively. The obtained result proves that the chosen subjects are relevant since they scored those sequences the highest. Moreover, the chosen subjects do not prefer 2D or 3D since both results are statistically the same. All HRCes except 15 and 16 can be divided into two groups. Odd numbers correspond to changing quality from 2D to 3D both for base layer. Even numbers are given to HRCes where the quality is changed from 3D base layer to 3D extended layer.

Odd HRC analysis proves once more that 2D and 3D with base layer result in poor quality. The reference point is HRC1, which corresponds to a 2D sequence encoded by base layer settings. All other odd HRCes are statistically the same. It means that adding from time to time 3D effect with low picture quality does not increases quality and should be avoided. Moreover, the results suggest that the quality in case of changing 2D to 3D is lower than of a constant 2D quality. The consequence from the system point of view is that, in case the available bandwidth is too low it is better to play 2D with base layer than turning 3D from time to time.

Even HRC analysis shows that adding better quality to a sequence from time to time does not decrease its quality. This conclusion is not obvious since quality blinking could be annoying. The obtained results indicate that temporal quality increase does not decrease quality; in some cases it increases the overall quality. An interesting observation is that for HRC 14 (only one segment is 3DBL) the obtained result is not statistically different from the perfect conditions. From the system point of view it means that, if the available bandwidth cannot guarantee that 3DEL can be downloaded during the streaming time it is still worth to play it from time to time.

V. CONCLUSION

In this paper, the results of the EU FP7 SARACEN ICT research project in quality-aware, adaptive 3D media distribution over P2P architectures were presented. In the paper, emphasis was given on the distribution of 3D video, supported by state-of-the-art techniques in both media coding (SVC) and media distribution (P2P). The result of the research is the knowledge of how to deliver 3D to the quality as high as possible. SARACEN forged results in the appropriate software, which improves image quality. The evaluation of results from the testing of the SARACEN platform have been presented, focusing on the behavior of the distribution system and the end-user terminals for providing QoE-aware 3D video playback in a non-quality guaranteeing environment such as the Internet.

The results give an indication about the behavior of video distribution systems in cases where adequate bandwidth for supporting 3D video transport is not guaranteed, and the decision of whether to switch between 3D to 2D video, or not, as well as the effect on the temporal quality change of the delivered 3D stream. Since the result of the project was an actual implementation of a media distribution platform that combined adaptive coding with P2P distribution, the actual value of the tests and the evaluation performed and presented is important as it takes into account an actual implementation, rather than simulations.

Though there is a long way towards a comprehensive evaluation of 3D video distribution platforms to become available, we believe that the results presented in this paper provide a valuable input and the basis for more comprehensive experiments, in different environments and coding solutions. In fact, industries, that can be the recipients of SARACEN studies, are unlimited. Nevertheless, first of all, the recipients are certainly television operators.

It is also planned to propose contributions to Video Quality Experts Group (VQEG), with a possible impact to ITU-T and/or ITU-R standardisation in the area of 3DTV quality. As for the time of preparation of this paper, the work is progressing and the authors are involved in that process. The results obtained in the SARACEN project psychophysical experiments, will be presented to VQEG. The contribution to a pair-comparison methodology will be of the special importance. Cooperation in the VQEG's pair-comparison test-plan is thus a major contribution from SARACEN.

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