DIstribution Of Multi-view Entertainment using content aware DElivery Systems

DIOMEDES

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Report on Special issue of Signal Processing: Image Communications journal on P2P distribution of 3D media

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Table of contents

List of Figures

1 INTRODUCTION

1.1 Purpose of the document

This document provides an overview of the accepted works to the special issue on P2P distribution of 3D media, published in Signal Processing: Image Communications journal. The main goal of that special issue is to investigate the related technologies and/or methods in the field of P2P video distribution (3D video distribution in particular). For this purpose, we provide the list of abstracts of the accepted papers along with our comments. A majority of the presented works presented in that special issue is related to the research conducted in DIOMEDES regarding P2P video delivery. In addition, we also present a summary of the joint contribution done by DIOMEDES partners to the special issue.

1.2 Notes on the report

As per the Description of Work of DIOMEDES, it was originally planned to attach a copy of the published special issue to this report. Unfortunately, heretofore the special issue has not yet been officially published and therefore we do not have access to the full text of the studies. The editor of the special issue (Dr Naeem Ramzan from Queen Marry University of London) has already been contacted to grant his permission on accessing to the abstracts of the accepted papers. He has kindly agreed to provide us with the list of the abstracts, which we use to generate this report.

Although we could not enlist the full features of these studies in this report, DIOMEDES consortium will continue to pursue the other studies in the special issue and will consider exploiting relevant research outcomes (techniques or tools), wherever applicable.

1.3 Structure of the document

This report is organized as follows: Section 2 provides the titles and the abstracts of accepted papers for publication. In this chapter, the main focus of the papers are highlighted and the studies that we will further investigate (when the full text is available) are underlined. Section 3 gives the details of the joint contribution done by DIOMEDES partners to the special issue. Finally, Section 4 draws the conclusions.

2 ACCEPTED PAPERS

In this section, short descriptions of accepted papers of other authors are listed.

2.1 Peer-to-Peer Multimedia Sharing based on Social Norms

2.1.1 Abstract

Designing incentive schemes for Peer-to-Peer (P2P) multimedia sharing applications, where the participating peers find it in their self-interest to contribute resources rather than to “free-ride”, is challenging due to the unique features exhibited by such networks: large populations of anonymous peers interacting infrequently, asymmetric interests of peers, network errors, multiple concurrent transactions, low-cost implementation requirements etc. In this paper, to address these challenges, we design and rigorously analyze a new family of incentive protocols that utilizes social norms. In the proposed protocols, each peer maintains a reputation reflecting its past behaviors in the P2P system (i.e. whether the peers have followed or not the social strategy prescribed by the social norm), and the social norm rewards and punishes peers depending on their reputations. We first define the concept of a sustainable social norm, under which no peer has an incentive to deviate from the social strategy prescribed by the protocol. We then formulate the problem of designing optimal social norms, which selects the social norm that maximizes the network performance among all sustainable social norms. In particular, we prove that, given the P2P network and peers’ characteristics, social norms can be designed such that it becomes in the self-interest of peers to contribute their contents to the network rather than to free-ride. We also investigate the impact of various punishment schemes on the social welfare as well as how should the optimal social norms be designed if altruistic and malicious peers are active in the network. Our results show that optimal social norms are capable of deterring free-riding behaviors and providing significant improvements in the sharing efficiency of multimedia P2P networks.

2.1.2 Comments

This study focuses on the incentive mechanisms that are commonly adopted in P2P solutions to overcome the problem of the free-riding, which corresponds to using the network resources without contributing to it. Although we do not expect to discover a significant work on adaptive video streaming in this paper, we will continue to investigate the work.

2.2 Video Streaming Over P2P Networks: Challenges And Opportunities

2.2.1 Abstract

A robust real-time video communication service over the Internet in a distributed manner is an important challenge, as it influences not only the current Internet structure but also the future Internet evolution. In this context, Peer-to-Peer (P2P) networks are playing an imperative position for providing efficient video transmission over the Internet. Recently, several P2P video transmission systems have been proposed for live video streaming services or video-on-demand services over the Internet. In this paper, we describe and discuss existing video streaming systems over P2P. Efficient (delay tolerant and intolerant) data sharing mechanisms in P2P and current video coding trends are elaborated in detail. Moreover, video streaming solutions (live and on-demand) over P2P from the perspective of tree-based and mesh-based systems are explained. Finally, the conclusion is drawn with key challenges and open issues related to video streaming over P2P.

2.2.2 Comments

This study presents the current state of the art video streaming technologies over P2P networks. Moreover, this work also introduces video coding aspects for video streaming. Therefore, we will closely investigate the publication and continue tracking the future publications of the authors.

2.3 Multiple Description Coded Video Streaming in Peer-to-Peer Networks

2.3.1 Abstract

It is known that in a peer-to-peer (P2P) network a peer node serves as both a receiver and a supplier, which enables uploading bandwidth of peer nodes to be utilized efficiently while relieving burden of the server node. This solves the scalability problem typically encountered in the traditional client-server model. However, frequent peer churn and varying bandwidth of peer nodes in P2P networks pose significant challenges for video streaming. These challenges can be addressed from both the P2P system design and the advanced video coding perspectives. In this paper, we first present a survey on the existing P2P video streaming systems that leverage the multiple description coding (MD coding or MDC) techniques, featured in providing strong error resilience for video delivery and supporting heterogeneity for peer nodes. Compared with layered coded video streaming, MD coded video streaming presents stronger robustness without requiring special provisions in P2P system design at a modest cost of compression efficiency, which is desirable in dynamic and error-prone P2P networks. In the MD coded video streaming, packet scheduling is critical to performance of mesh-based P2P systems. A new packet scheduling framework is formulated for receiver-driven MD coded video streaming, where a receiver collects peer nodes' information and generates a transmission schedule for MDC packets. In the proposed framework, a rate-distortion optimized packet selection scheme is developed to minimize the expected distortion subject to limited downloading bandwidth. Accordingly a rate-distortion based prioritized peer selection scheme is employed to choose an appropriate peer node for each of the selected packets. Simulation results validate the effectiveness of the proposed scheduling scheme and the advantage of MDC over layered coding in a network with frequent peer churn.

2.3.2 Comments

This work focuses on multiple description coding, a key strategy that is adopted in DIOMEDES P2P as well. Therefore, we will closely investigate the work and understand what kind of MDC scheme they are utilizing. There are three very important aspects of MDC: i) Redundancy, ii) Quality of individual descriptions iii) The packetization and request mechanism. We will try to obtain as much information as possible on these subjects.

2.4 A Study of an Hybrid CDN-P2P System Over the PlanetLab Network

2.4.1 Abstract

In this work we propose an hybrid CDN-P2P architecture for video contents delivery based on the NextShare platform. Experiments were conducted over the PlanetLab network using a number of peers which encompass real network behaviors. Results show that although the NextShare is based on the original BitTorrent file sharing mechanism, the implemented tools can efficiently deliver video over a heterogeneous and time varying network if peers can rely on an intermediate distribution layer between the CDN and the final users. Among the other benefits, CDN edge servers are significantly offloaded and peers can experience low start-up delays. Architecture design and simulation results are taking place in the context of the European FP7 project COAST.

2.4.2 Comments

We have already been closely investigating the work in P2P-Next project (i.e., NextShare platform). This work seems quite parallel to the DIOMEDES architecture, in which P2P works together with the main servers (CDNs). Therefore, we will investigate the full text. We will focus on the load balancing between P2P and CDNs in particular. In DIOMEDES, we try to minimize the server load by using intelligent chunk scheduling operations.

2.5 A Bayesian approach for user aware peer-to-peer video streaming systems

2.5.1 Abstract

Peer-to-Peer (P2P) architectures for live video streaming has attracted a significant attention from both academia and industry. P2P design enables end-hosts to relay streams to each other overcoming the scalability issue of centralized architectures. However, these systems struggle to provide a service of comparable quality to that of traditional television. Since end-hosts are controlled by users, their behavior has a strong impact on the performance of P2P streaming systems, leading to potential service disruption and low streaming quality. Thus, considering the user behavior in these systems could bring significant performance improvements. Toward this end, we propose a Bayesian network that captures all the elements making part of the user behavior or related to it. This network is built from the information found in a cross-analysis of numerous large-scale measurement campaigns, analyzing the user behavior in video streaming systems. We validate our model through intensive simulations showing that our model can learn a user behavior and is able to predict several activities helping thus in optimizing these systems for a better performance. We also propose a method based on traces collection of the same user type that accelerates the learning process of this network. Furthermore, we evaluate the performance of this model through exploring its applications and comparison with non-contextual models.

2.5.2 Comments

This study focuses on predicting the behaviour of peers and using this information in the decision making process of chunk requests. While there are numerous similar studies, we are a bit sceptical in the process of interpreting the behaviour of peers, especially over the Internet. This is mostly due to the chaotic behaviour of the users and the link states. So far in the area of video streaming, people are using trace documents that are captured before hand to test the performance of the received video however using such a learning mechanism seems a bit impractical (at least for the scope of project DIOMEDES).

2.6 Peer-to-Peer Streaming in Heterogeneous Environments

2.6.1 Abstract

Peer-to-peer overlay networks are comprised of different kinds of devices, from mobile phones to high-definition televisions. They differ in size, computational power, and Internet access. The design of any peer-to-peer system has to account for such heterogeneous environments. For example, in the context of content delivery systems, the content must be delivered reliably, on time, and in a format suitable for each peer.

This work addresses the heterogeneity and reliability of peers in peer-to-peer streaming applications. It applies lessons learned from distributed hash tables (DHTs) by adopting a prefix-based overlay structure. The fexibility of its neighbor selection policy is exploited to make use of scalable coding and erasure coding schemes, bringing different kinds of peers together in a single overlay network. Thereby, each peer can select the appropriate number of scalable coding layers to obtain content in a suitable format. The prefix-based nature further allows efficient content distribution with low-delay, simple maintenance, strong connectivity, and quick adaption to changing conditions; making the proposed algorithms desirable for real-world use, for both peer-to-peer live and on-demand streaming.

2.6.2 Comments

This work focuses of adaptive streaming of scalable video. This is one of the main subjects of DIOMEDES P2P and therefore we will investigate the full text thoroughly.

2.7 Multi-Stream 3D Video Distribution over Peer-to-Peer Networks

2.7.1 Abstract

The recent advances in stereoscopic video capture, compression, and display have made 3 Dimensional (3D) video a visually appealing and costly affordable technology. There have been a series of pioneer works on streaming 3D video over the Internet. Yet the remarkably increased data volume of 3D videos poses great challenges to the conventional client/server design, which has already suffered from supporting 2D videos.

In this paper, we present an initial attempt toward efficient streaming of 3D videos over a peer-to-peer network. We show that the inherent multi-stream nature of 3D video makes playback synchronization more difficult, which is particularly acute with the existence of multiple senders in a peer-to-peer overlay. We address this by a novel 2-stream 2-stage buffer design, together with weighted data scheduling and light-weight synchronization. We further discuss a series of key practical issues toward implementing our peer-to-peer 3D video streaming system, including the weight modeling for data segments, the interactions with the RTP/RTCP protocol stack, and the inter-operability with monoscopic video as well as extension to multi-view video. We have evaluated the performance of our system under different end-system and network configurations with typical 3D video streams. The simulation results demonstrate the superiority of our system in terms of both scalability and streaming quality.

2.7.2 Comments

This is the only paper that has 3D component in it. The authors have mentioned the RTP/RTCP protocol stacks, which are designed for server-client based protocols. Therefore, we predict that the authors are using a tree-based distribution system, in which data is forwarded from one peer to another in a server-client fashion. There are well-known problems of tree-based solutions, such as scalability and tree maintenance. Although the authors have commented that it is an initial attempt toward 3D video streaming, the work is of interest to us.

2.8 Server-Assisted Adaptive Video Replication for P2P VoD

2.8.1 Abstract

In recent years, Peer-to-Peer assisted Video-on-Demand (P2P VoD) has become an effective and efficient approach to distribute high-quality videos to large number of peers. In a P2P VoD system, each peer contributes storage to store several videos to help offload the server. The replication strategy, which determines the videos to be stored at each peer’s local storage, plays an important role in system performance. There are two approaches: (a) Solve a huge combinatorial optimization problem; (b) Use simple cache replacement algorithms, such as Least-Frequently-Requested (LFR) or FIFO. The first approach needs to collect a large number of parameters whose values may be changing, and use some approximation method (such as linearization) to solve the optimization problem, both aspects have accuracy issues. In the second approach, a peer replaces some video in the cache with the currently viewed video, based on local information. While it is simple, we show their performance can be improved by a little centrally collected state information.

Specifically, the needed feedback information is the current downloading rate provided by peers for each video. In this paper, we describe a hybrid replication strategy, and give detailed description of how the server collects and maintains the feedback information, and how peers use that information to determine what videos to store and indirectly control their uplink bandwidth contribution. This explains why the hybrid strategy is much simpler and more practical than the combinatory optimization approach. We then use simulation to demonstrate how our scheme out-performs the simple adaptive algorithms. Our simulation results also demonstrate how our scheme is able to quickly respond to peer churn and video popularity churn.

2.8.2 Comments

This work focuses on a distributed storage mechanism for serving multimedia over P2P networks. The work is not too relevant to the scopes of DIOMEDES, because we are using a centralized mechanism for initial seeding.

2.9 Redundancy Controllable Scalable Unbalanced Multiple Description Bitstream Generation for Peer-to-Peer Video Streaming

2.9.1 Abstract

In peer-to-peer video streaming, the robustness to peer and packet losses is regarded very important in order to enjoy a good quality of experience. Multiple description coding (MDC) schemes are known to provide high robustness to packet losses. In peer-to-peer streaming in addition to high robustness, efficient controllability of data rate and redundancy among the data streams from peers is also vital. In this paper, a novel framework for scalable multiple description coding scheme for peer-to-peer video streaming is presented by addressing these requirements. The proposed MDC solution is based on the multiple description scalar quantization (MDSQ) by addressing the joint decoding of unbalanced descriptions and addition of jointly decodable successive refinement layers to side descriptions. Firstly, the design conditions for MDSQ with constrained successive refinement to obtain scalable multiple description streams where the bit streams can be truncated at any point to obtain lower quality spatial temporal descriptions are firstly proposed.

Then the design conditions for joint decoding of two or more side descriptions from different multiple description scalar quantizers, originating from various bin spread factors leading to controllable redundancy are proposed. These design conditions enable joint redundancy and date rate control for streams coming from different peers, thereby, enabling high robustness to packet losses as well as peer losses with the adaptability of redundancy levels and truncation of scalable streams. The proposed design constraints are used within the motion compensated temporal filtering (MCTF) framework to demonstrate its advancement in robust peer-to-peer video streaming. The results show significant improvements over conventional MDC based on simple MSDQ and over single description scalable video.

2.9.2 Comments

This is another work on MDC for P2P networks. We will investigate the full text.

2.10 A Game Theoretic Approach to Minimum-Delay Scalable Video Transmission over P2P

2.10.1 Abstract

In this paper we describe a game theoretic framework for scalable video streaming over a peer-to-peer network. The proposed system integrates minimum delay functionalities with an incentive provision mechanism for optimal resource allocation. First of all, we introduce an algorithm for packet scheduling that allows users to download a specific sub-set of the original scalable bit-stream, depending on the current network conditions. Furthermore, we present an algorithm that aims both at identifying freeriders and minimising the transmission delay. Uncooperative peers are cut out of this system, while users upload more data to those which have less to share, in order to fully exploit the resources of all peers. Experimental evaluation shows that the proposed model can effectively cope with free-riders and minimise the transmission delay for scalable video transmission by exploiting a packet scheduling algorithm, game theory, and a minimum-delay algorithm.

2.10.2 Comments

This work focuses on *packet* scheduling for P2P networks and tries to minimize the dedicated resources for free-riding peers. Based on the terminology, we believe that the authors are not using a chunk-based system. Nevertheless, their work has similar goals as DIOMEDES and therefore we will investigate the full text.

2.11 Robust Mobile Video Streaming in a Peer-to-Peer System

2.11.1 Abstract

In a peer-to-peer (P2P) video streaming system, peers not only consume video, but also route it to other peers in the system, where ordinary peers are assumed to have sufficient downlink speed and media capability. This assumption often fails when the P2P system consists of peers that are heterogeneous in their computing power, hardware, and media capability.

In this paper, we address a problem of streaming video to mobile devices, which are less capable than ordinary peers. In order to stream video to mobile devices, transcoding is often required to render video suitable for their small display, limited downlink speed, and limited video decoding capability. However, performing transcoding at a single peer is vulnerable to peer churn, which leads to video disruption. We propose interleaved distributed transcoding (IDT), a robust video encoding scheme that allows peers more capable than mobile devices to perform transcoding in a collaborative fashion. IDT is designed in such a way that transcoded substreams are assembled into a single video stream, which can be decoded by any H.264/AVC baseline profile compliant decoder. Extensive simulations and its implementation in a real P2P system demonstrate that the proposed scheme not only reduces computational load at a peer but also achieves robust streaming in case of peer failure or packet loss due to adverse wireless channel conditions. We confirm this finding by analyzing the effect of distributed transcoding under peer failure.

2.11.2 Comments

This work focuses on content adaptation for mobile devices that has limited processing and storage capabilities. For this purpose, they are utilizing transcoding to reshape the content in a way that is suitable for the target device capabilities. From many aspects, this type of approach is not suitable for DIOMEDES. First, the content validation is difficult to perform in a scenario, in which peers modify the received content (i.e., transcoding). Besides, it seems like authors are using a tree-based solution, as otherwise controlling “who will transcode which section of the content” would be a very difficult challenge to address. A different approach could have been using Scalable Video Coding and forwarding a suitable layer for terminal adaptation.

2.12 A Game Theoretic Approach To Video Streaming Over Peer-To-Peer Networks

2.12.1 Abstract

We consider the problem of foresighted multimedia resource reciprocation in peer-to-peer (P2P) networks, which consist of rational peers aiming at maximizing their individual utilities. We introduce an artificial currency (credit) to take into account the characteristics of different parts of the video signal. The resource reciprocation with the proposed credit metric can be formulated as a stochastic game, in which the peers determine their optimal strategies using Markov Decision Process (MDP) framework. The introduced framework can be applied to the general video coding, and in particular, is suitable for the scalable video where various parts of the encoded bit stream have significantly different importance for the video quality.

2.12.2 Comments

We conclude that the scope of the proposed work is not in line with that of DIOMEDES. Hence, this paper will not be further elaborated.

3 DIOMEDES CONTRIBUTION

In this section, a shortened version of DIOMEDES's joint contribution to the special issue is presented. Please note that the full "camera-ready" version of the paper is provided in the Annex of the report.

3.1 Adaptive Streaming of Multi-View Video over P2P Networks

3.1.1 Introduction

This paper proposes a novel solution for the adaptive streaming of 3-D representations in the form of Multi-view video by utilizing P2P overlay networks to assist the media delivery and minimize the bandwidth requirement at the server side. Adaptation to diverse network conditions is performed regarding the features of human perception to maximize the perceived 3D. Subjective tests are performed to characterize these features and determine the best adaptation method to achieve the highest possible perceived quality. Moreover, a novel method for mapping from scalable video elementary stream to torrent-like data chunks is proposed for adaptive video streaming and provide an optimized windowing mechanism that ensures timely delivery of the content over. The paper also describes the techniques generating scalable video chunks and methods for determining system parameters such as chunk size and window length.

3.1.2 3D Perception Issues Related to Adaptive Streaming of MVV

The adaptation engine of the proposed P2P solution takes into account the perception of 3D video by humans in making the rate adaptation decisions. The most prominent perceptual attributes of 3D video are depth perception, picture quality (including blocking and blurring), and visual fatigue. Overall, this can be referred as the perceptual quality of 3D viewing experience (QoE). There has been some previous research on assessing the perceived quality of 3D videos objectively, targeting high correlation percentages with the subjective opinion. It should be noted that the overall 3D QoE depends on multiple factors, some of which are independent of the coding and transmission aspects, such as the way the 3D video content is recorded and post-processed and displayed. The main goal of this section is to evaluate effects of scalable multi-viewpoint coding, packet losses, and adaptation strategies on the perception of QoE.

3.1.2.1 3D Perception of Packet Losses

Packet losses are inevitable in IP networks. So far, researches have mostly focused on perception of 3D video without packet losses, investigating different encoding options such as asymmetric rate allocation. Most of the studies reveal that human visual system (HVS) tends to neglect loss of high frequency components in one of the views [1], [2]. However, the effect of packet losses/delays over visual perception of 3D video and whether HVS can compensate the artifacts generated by concealment methods has not been studied. Since lost data significantly affects the perception error concealment at the receiver side is an important issue for transmitting MVV over IP.

One important factor that can play a key role in this experiment is the implementation of error concealment algorithm. Two different error concealment methods are compared; slice level error concealment algorithm based on slice repetition and frame repetition. First approach performs well for slices that has limited or no motion, but introduces distortions when there is a significant motion within the lost slice's region. In the subjective tests on comparison of two methods, people have preferred slice based error concealment method even in sequences with high motion and disturbed by frame repetition.

Second factor is the duration of error and whether it affects both views or not. Normally, due to bursty nature of packet losses over the IP [3], the errors that occur for a time interval, effects both views. But it is possible to delay one of views or interleave its data in a way that different sections of the data are transmitted at a time instant. In this case longer interval of the video becomes erroneous but the errors are more likely to be separated over different intervals. The subjective tests, that are performed to find out if HVS favors one of these cases, reveal that even though the error interval has been extended, people significantly prefer the second option. This finding affects the P2P chunk scheduling proposed in this paper.

3.1.2.2 3D Perception of View and Depth Adaptation

In the scope of medium term and long term 3DTV applications, depth maps seem to be a dominant part of the 3D video format delivered to homes. The existence of more than two viewpoints, alongside with their depth components will necessitate view adaptation from time to time, especially when network congestions are observed. Missing views will either be discarded or interpolated using the existing viewpoints. There is not enough research in the literature that investigates adaptation through defining the color and depth priorities, as well as view scaling and quality scaling priorities, targeting the ultimate perception of resultant stereoscopic video. In this study, a series of experiments are performed to investigate the useful bandwidth adaptation approaches in the scope of depth based stereoscopic video format comprising two view-plus-depth pairs (referred to as MVD2 from onwards). MVD2 is encoded using SVC, using a single or two quality layers, based on a particular coding scheme. This scheme comprises asymmetric SVC for both color and depth components. The effectiveness of utilizing asymmetric coding in adapting stereoscopic video was formerly reported [4] for conventional stereoscopic 3D. In this scenario, one of the pairs is encoded with a single layer (reasonably high quality) and the other pair is encoded with two quality layers. In times of network congestion, the layered pair is scaled. The PSNR results of the experiment between both adaptation scenarios suggest that at harsh network conditions, such as when the streamed 3D video needs bandwidth scaling to a large extent, view adaptation (second scenario) may offer a better stereoscopic viewing performance. One reason for this result is that the delivered pair of color and depth video at highest quality can lead the HVS and may hide the degrading effects of occlusion estimation in the estimated stereo pair. Nevertheless, when the fluctuations in the available transmission bandwidth are not as extensive as experimented in this case, the choice of adapting the quality of color and depth video streams would be sensible to not to neglect a complete view stream at the expense of losing occlusion information.

3.1.3 Adaptive MVV Streaming over P2P Networks

For 3D multimedia transmission, design should also consider the perception of 3D media and perform adaptation decisions accordingly to provide highest QoE. In this proposition, the application is network aware, as it creates chunks considering the characteristics of networking layer transport protocol. In this part, first a chunk generation method is proposed then it presents a window based adaptive streaming/scheduling algorithm that respects both the video coding concerns and the perception of 3D video prone to IP errors.

3.1.3.1 Generation of Chunks for Adaptive Streaming

Packetization of multimedia content considering the underlying network infrastructure has a critical impact over the performance of any streaming solution [5]. For a Torrent based P2P system, packetization corresponds to formation of chunks. This paper proposes a method using the SVC encoded bitstream and splitting that stream at group of pictures (GOP) boundaries so that each received chunk can be decoded, because each GOP starts with an intra-coded frame (I-frame) Figure 1. The SVC stream starts with header NAL Units consisting of Supplementary Enhancement Information (SEI), Sequence Parameter Set (SPS) and, Picture Parameter Set (PPS). The headers provide vital information such as picture resolution in macroblocks (MB) and decoded picture buffer size. When slice mode is disabled there is one base layer NAL unit and one enhancement layer NAL unit for each frame. If the enhancement layer is lost, the remaining stream is still useful in generating frames but at a lower quality, indicating that enhancement layer NAL units are discardable. Therefore, the base and enhancement NAL units are splitted into separate chunks.

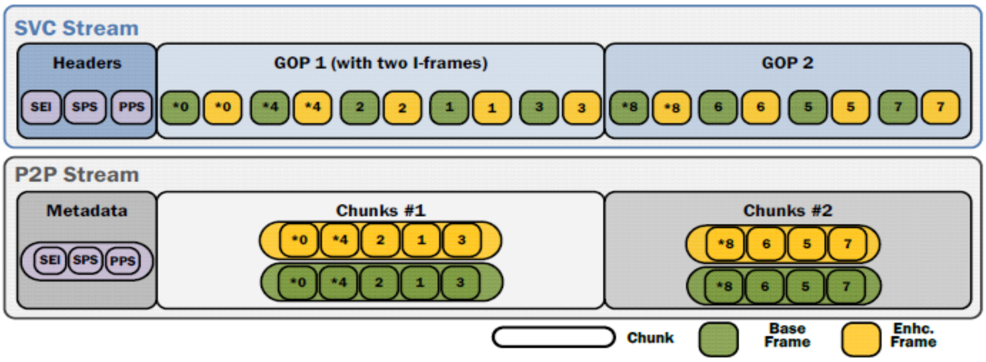

Figure 1: Chunk generation using one GOP per chunk (GOP size is 4 frames)

3.1.3.2 Quality Adaptation and Chunk Scheduling in MVV P2P Streaming

Temporal windowing mechanism which is the most widely accepted approach for timely delivery is extended in two additional dimensions The first dimension is number of views meaning that there are separate windows for each view and depth-map. The second dimension is to represent the importance level (discardibility) of the chunks to enable adaptive streaming as depicted in Figure 2. In this model, all base layer chunks must be requested prior to enhancement layer chunks. With this approach, the scheduling mechanism tries to ensure smooth video playback and high quality when possible. Using the visual test results in the previous section, it is stated that if one of the adjacent views has slice or packet loss then it is possible. This result can be exploited in the following way. When choosing chunks that are going to be downloaded for adjacent views, it is best to choose them for different time instances because if a chunk is lost (in UDP) or delayed (in TCP) then it may be possible to conceal it using adjacent view to a certain extend. In the other case when equal time instances are requested for each view), if the available bitrate is low, then it is more likely to experience packet losses in all view, making artifacts more perceivable.

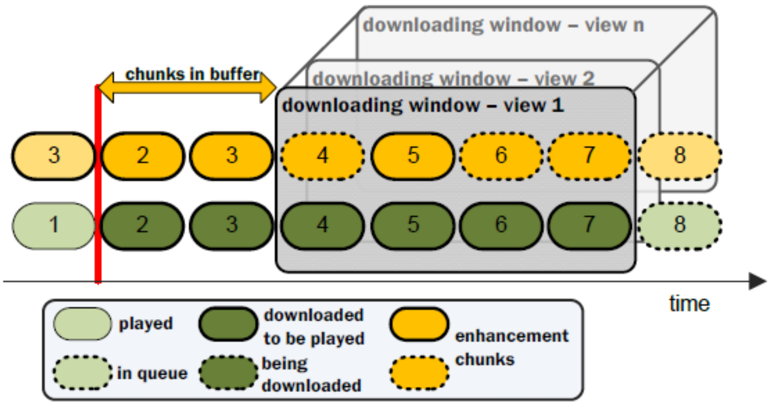

Figure 2: Downloading window with two layers
(The red line indicates current location of the player.)

3.1.4 Defining System Parameters of P2P System

3.1.4.1 Chunk Length

Choosing size of video chunks too short or too long affects the adaptation capability and transmission efficiency. With experiments in a controlled LAN environment, chunk size are tried to be optimized according the characteristics of TCP. The drawback of TCP is it takes some time before incrementing size of its output buffer. Therefore, if the transmission occurs in a shorter interval, then TCP cannot fully utilize the link capacity. This result indicates that, a protocol that transmits data less than 1 second may have result in underutilization of the network. Therefore, it can be concluded that the number of GOPs per chunk should be set such that it includes duration of 1 second.

3.1.4.2 Window Size

The size of the downloading window has an effect on two important system features, one explicit and one implicit. The explicit one is the pre-buffering delay. Longer window size requires higher pre-buffering delay because chunks within the windows are streamed in random order and needs to be completed before sequential playback. Secondly, the window size affects workload on the server side. If the window size is long there is a higher chance that peers will request different chunks from the server, allowing more chunks to be exchanged among peers. The networking test results clearly indicate that the longer window size allows higher sharing rate among peers. If the bandwidth requirement is above the link capacity then peers starve and experience lost base layer chunks. However, if the window size is large enough than additional peers can be compensated meaning that bandwidth cost of the peers can be reduced by increasing the pre-buffering time. The increase in window size also augments the reception of enhancement layers because increase P2P activity allows additional data to be transmitted from the server side.

3.1.5 Conclusion

IP offers flexible channel capacity to delivery MVV which has varying bitrate requirement based on the number of views transmitted. In order to provide a more scalable delivery in terms of increasing number of users, it is proposed a P2P streaming solution based on successful file sharing protocol, Bittorrent. We extend the Bitttorent approach with a windowing mechanism to enable both adaptive streaming and control the workload of the server side. We have also identified the effect of system parameters such as chunk and window size. We have shown that increasing the window size augments the video quality but introduces pre-buffering delay, which indicates a trade-off. A solution over IP should consider characteristics of the networking protocol to achieve the highest throughput. In this sense, the proposed solution is cross-layer architecture in which application and transport layers work in harmony to provide the best perceived quality. In short, the application layer generates discardable chunks so that the transport layer may omit them in the case of bandwidth scarcity. Moreover, the application layer generates the chunks at a size that minimize side effects of using TCP such as slow start. The proposed solution also regards perception of 3D video by HVS that suggest a new type of scalability option, view-scalability. Tests regarding perception of 3D video in the case of packet loss are provided and propose a new scheduling algorithm to increase the QoE.

4 CONCLUSIONS

In this report, we have identified the key studies in the special issue that could be useful for the DIOMEDES P2P. Unfortunately, by the time this deliverable was written, we did not have access to the full text of the papers, since the publisher did not release the issue officially. However, we have received the list of abstracts of the accepted papers that we provide in Section 2 along with the comments about their usefulness. In Section 3, we have provided a brief summary of the joint work that is submitted by UNIS and KU.

We will continue to investigate the studies presented in this special issue as well as in other journals and conferences to be aware of the state of the art research about P2P video streaming.

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Appendix A: Glossary of abbreviations

C	
CDN	Content Distribution Network
D	
DHT	Distributed Hash Tables
F	
FIFO	First in First out
G	
GOP	Group of Picture
H	
HVS	Human Visual System
I	
IDT	Interleaved Distributed Transcoding
L	
LFR	Least-Frequently-Requested
M	
MB	Macroblock
MCTF	Motion Compensated Temporal Filtering
MDC	Multiple Description Coding
MDP	Markov Decision Process
MDSQ	Multiple Description Scalar Quantization
MVV	Multi-View Video
N	
NAL	Network Abstraction Layer
P	
P2P	Peer to Peer
PPS	Picture Parameter Set
PSNR	Peak Signal to Noise Ratio
S	
SEI	Supplementary Enhancement Information
SPS	Sequence Parameter Set
Q	
QoE	Quality of Experience
R	
RTP	Real-time Transport Protocol
RTCP	Real-time Transport Control Protocol
S	
SVC	Scalable Video Coding
V	
VoD	Voice on Demand

Appendix B: Accepted Paper from DIOMEDES

Adaptive Streaming of Multi-View Video over P2P Networks

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Abstract

In this paper, we propose a novel solution for the adaptive streaming of 3-D representations in the form of Multi-view video by utilizing P2P overlay networks to assist the media delivery and minimize the bandwidth requirement at the server side. Adaptation to diverse network conditions is performed regarding the features of human perception to maximize the perceived 3D. We have performed subjective tests to characterize these features and determine the best adaptation method to achieve the highest possible perceived quality. Moreover, we provide novel method for mapping from scalable video elementary stream to torrent-like data chunks for adaptive video streaming and provide an optimized windowing mechanism that ensures timely delivery of the content over. The paper also describes the techniques generating scalable video chunks and methods for determining system parameters such as chunk size and window length.

Keywords: *P2P overlay networks, multi-view video, adaptive streaming, scalable video chunks, 3D video perception*

1. Introduction

Stereoscopic video has already made an impact on the multimedia industry. The market share of stereoscopic 3D movies in Hollywood has increased significantly over the last few years. More recently, stereoscopic TV broadcasts over DVB have begun in the UK in April 2010 using a frame-compatible format, which combines right and left views of a stereoscopic video pair in a single HD video frame. 3D-compatible TV sets that can display stereoscopic video using various technologies, such as using polarization or time-shutter glasses, are available in the market. Meanwhile, standards for transmitting 3D media signals over peripherals, such as HDMI 1.4a, have been defined.

We are now progressing to the next phase in 3D media services, which will be based on Multi-View-Video (MVV) formats. MVV enables viewing a scene in 3D from multiple angles (within a viewing cone), which may make it possible to see behind an object by tilting the head; whereas in stereoscopic video, the viewer can only see what has been captured from a single viewpoint. Moreover, MVV displays are auto-stereoscopic which do not require wearing special 3D glasses. The major difficulty with MVV is that the amount of data; hence the bit-rate required to transmit it, depends on the number of views; making it difficult to transmit over fixed bit-rate channels, such as the DVB. Transmission of MVV over IP (Internet Protocol) is perhaps the most flexible solution for 3D media delivery, which can provide different transmission rates to different users according to their available connection rate and display technology. In addition, it is also possible to receive feedback from the user over an IP channel, enabling effective rate adaptation in addition to personalized services such as user centric advertisements or interactive TV. The MVV over IP can be offered as a stand-alone service or as a supplement to broadcast of stereoscopic video over DVB.

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[2] A. Murat Tekalp also acknowledges support from Turkish Academy of Sciences (TUBA)

It is well-known that video over IP has some limitations. First, IP operates in the best effort sense; hence, it is possible to experience packet losses and varying amount of delays between end nodes. Second, the server-client architecture is not scalable with the number of users and the data rates required for MVV services put extra burden on the server. Fortunately, it is possible to overcome the former problem by using adaptive streaming and scalable video coding techniques, and the latter problem by using a peer-to-peer streaming architecture. In an adaptive streaming solution, the video send-rate is dynamically adjusted according to the available user link capacity. There has been significant research effort in adaptive streaming using multiple rate simulcast encoding or scalable video coding (SVC), and there are already successful commercial adaptive streaming solutions based on the server-client model, such as Microsoft's silver-light technology [1]. However, adaptive video streaming based on the P2P streaming model remains an open and active research area.

This paper proposes a framework for adaptive streaming of MVV using a server-assisted P2P overlay over IP. A centralized server will assist P2P service start-up and in case of failures, such as ungraceful peer exit. Moreover, the centralized server may handle authentication, copyright management and user permissions. Although authentication service is very critical, it requires negligible bandwidth compared to 3D media transmission and can be handled by a centralized solution. In the literature, most studies on P2P video neglect issues related to video coding, which has critical impact on the efficiency of the solution. We believe that a successful P2P video streaming system should employ a cross-layer solution, in which the network layer is video coding aware. Especially in 3D video, different components of the MVV format, such as different views and their depth maps, and possibly different video layers depending on their depth and geometry, affect the overall perception of 3D video experience differently. Hence, it is natural to consider unequal encoding and/or adaptation priority for them. Therefore, our adaptive P2P streaming solution carefully considers 3D perception issues specific to MVV, such as the effect of view and depth adaptation and the effect of packet losses in designing the proposed adaptation strategies. The rest of this paper is as follows: Section 2 provides an overview of the state of the art in 3D video coding and P2P networking. We provide a detailed description of the proposed framework in Section 3, including scalable chunk generation and rate adaptation strategies. In Section 4, we discuss 3D perception of MVV related to rate adaptation. Section 5 describes tests performed over an actual IP network to evaluate the performance of the proposed server-assisted adaptive P2P solution and the proposed adaptation strategies. Finally, in Section 6, we draw conclusions.

2. The State of the Art

2.1. Multi-view Video Formats

Multi-view video can be represented by a raw collection of views or can be enhanced by depth information in order to enable artificial view synthesis. The latter is often called the view-plus-depth format. The view-plus-depth format was first proposed to represent stereo video by a single view and its associated depth information by the European project Advanced Three-Dimensional Television System Technologies (ATTEST) [2] in order to develop a 3DTV service which is backwards compatible with the standard monocular TV. MPEG has specified a container format for view-plus-depth stereo video in "ISO/IEC 23002-3 Representation of Auxiliary Video and Supplemental Information" also called MPEG-C Part 3 [3] [4]. It has later been proposed to extend this format to multi-view-video-plus-depth (MVD), where N views and N depth maps are used to generate M views at the decoder, where $N \leq M$ *[5]*. Naturally, the algorithms to estimate the depth maps can be run at the receiver side . However, this process requires the knowledge of camera calibration parameters and also significant computation power that can make it computationally infeasible to perform in real-time without specialized hardware.

2.2. Multi-View Video Coding

There are two main options using open codec standards for adaptive streaming:: i) *Simulcast encoding* using scalable extension of H.264/AVC, called SVC, which allows SNR, temporal or spatial scalability. ii) *Dependent encoding* using the multi-view extension of H.264/AVC, called MVC, which can exploit inter-view redundancies and provide higher encoding efficiency compared to simulcast coding. Note that the depth maps associated with each view may or may not be encoded as auxiliary data in both options. More detailed information on 3D video coding can be found in the literature [6].

In simulcast coding, each view is coded independently without exploiting similarities between views. This approach allows independent transmission and decoding of streams, eliminating possible complexities especially in P2P solutions. One option to achieve scalable coding is to utilize SVC extension of H.264/AVC standard that provides spatial, temporal and quality scalability [7]. When compared against the H.264/AVC standard, the SVC extension provides better QoE in the case of limited resources such as link capacity, processing power and display size. It has backward compatible syntax that has been standardized by the Joint Video Team (JVT) of the ITU-T VCEG and the ISO/IEC MPEG. For backward compatibility, SVC has a layered structure with base layer that is complaint with the H.264/AVC syntax and discardable enhancement layer that increases the quality in either one the scalability dimensions.

MVC extension of H.264/AVC offers the best compression efficiency for MVV by dependent coding among views to exploit similarities between them [8]. It features flexible prediction structures, allowing frames to be predicted from all neighboring frames in both time and view dimension (full prediction) [9][10]. In the other extreme, it is possible to remove all inter-view dependencies, resulting in simulcast coding. One commonly used prediction structure is known as simplified prediction scheme that restricts inter-view prediction to certain time instants. It provides similar rate-distortion (RD) performances with full prediction [11] with far fewer inter-view dependencies. The encoding efficiency of MVC is highly affected by lightning conditions, camera orientation (disparity) and noise.

In multi-view-plus-depth encoding, selected views and associated depth maps can be can either simulcast or dependently encoded using non-scalable or scalable codecs. It is also possible to exploit correlations between the texture video and associated depth maps. For example, SVC is employed to compress texture videos and associated depth maps jointly, where up to 0.97 dB gain is achieved for the coded depth maps, compared with the simulcast scheme [12]. Joint coding approaches most commonly target sharing some entities between the color (view) component and the depth component, such as the motion vectors. Nevertheless, there are some handicaps in making use of shared motion vector information between the two components. One of them is that the motion vectors computed during rate-distortion optimization process are selected to minimize the energy of the texture residual, which does not show 100% correlation for two components. In addition, the motion in the third dimension also affects the luminance of depth pixels and this is why there is the need for compensating the motion in Z-direction for depth maps. A previous work by Kamolrat, et. al, has investigated the utilization of motion search in the third dimension (in addition to 2D motion estimation) to further increase the block based depth map coding performance [13]. A previous research work had also utilized SVC in the scope of coding backwards-compatible view-plus-depth map content, such that the view was put in the base layer, and the depth map was put in the enhancement layer without inter-layer prediction [14].

2.3. Torrent-based P2P video streaming

P2P solutions can be classified as tree-based, mesh-based, or hybrid in terms of link formation [15]-[17]. In theory, tree-based solutions may be efficient in terms of message traffic but their rigid form is difficult to maintain and media delivery may get interrupted in case of a single peer exit. Moreover, this approach assumes that every peer can upload video to at least one peer at the same rate that it receives video, which is difficult due to commonly used asymmetric connections with less uploading capability than downloading capacity. Consequently, a purely tree based P2P distribution system is not realistic.

Among the mesh-based approaches, the Torrent protocol is one of the most successful for P2P file/media sharing. In Torrent, data is partitioned into chunks, and chunks are exchanged between peers. A peer that has all chunks is called a seeder, whereas peers with missing chunks are called leechers. Seeders and leechers form P2P swarms, a self-organizing mesh network. The ratio of seeders to leechers is a critical parameter for the maintainable rate of P2P data sharing. In the Torrent protocol, a metadata file contains hash values of each chunk to provide data integrity. The metadata file also provides the address of peer tracking server(s), called tracker(s), so that a newly joining peer can connect to a tracker to get a sub-list of other peers in the swarm. There are newer methods that enable trackerless-mode such as distributed hash tables (DHT) [18] and peer exchange (PEX) [19]. Torrent is used for lossless data delivery with no sense of timeliness, assuming that the data will be used once the whole file is downloaded. The chunk picking strategy is built on rarest first policy in which peers favor chunks that are least spread within the swarm. By this way, such chunks become more accessible but the ordering of the chunks is disregarded, so peers receive chunks in random order. Naturally, it is not possible to deliver time sensitive data, such as multimedia using this policy.

There are many propositions to enable video delivery using the Torrent protocol in a timely manner. The most widely accepted approach seems to be a temporal windowing mechanism so that peers can only request chunks which are in near future of the current play-out time as shown Fig. 1. This window defines the ids of a variable number of chunks that a peer may request in random order. If there is no randomness, then all peers may request chunks in the same order. Then it is more unlikely that peers will have unique data to exchange among themselves. Instead, they may end up requesting all chunks from the seeder one by one, unless some peers have significantly higher download rates. But if the chunks are downloaded in random order, then leechers may also contribute to data dissemination. The drawback of windowing is that, it forces a pre-buffering delay before starting the play-out. The relationship between buffering and size of the window has been investigated in Section 5.3.

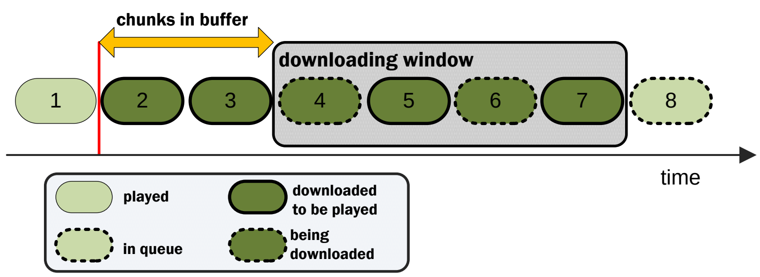


Fig. 1: A sample downloading window with 2 downloaded and 2 remaining chunks. (The red line indicates current location of the player.)

3. 3D Perception Issues Related to Adaptive Streaming of MVV

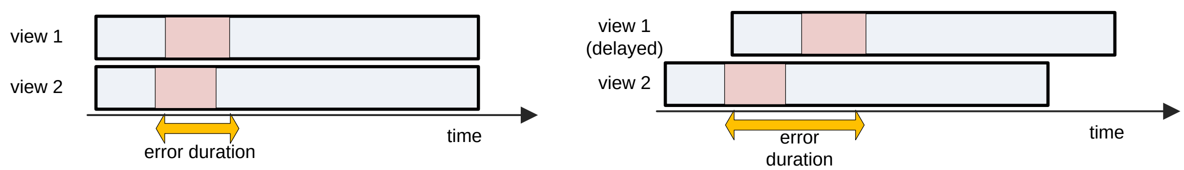
The adaptation engine of the proposed P2P solution should take into account the perception of 3D video by humans in making the rate adaptation decisions. The most prominent perceptual attributes of 3D video are depth perception, picture quality (including blocking and blurring), and visual fatigue. Overall, this can be referred as the perceptual quality of 3D viewing experience (QoE). There has been some previous research on assessing the perceived quality of 3D videos objectively, targeting high correlation percentages with the subjective opinion. In a previous study, [20] authors have briefly listed a number of approaches for the objective 3D video quality assessment. However, no such objective measure has been widely accepted or adopted in the community. Subjective testing is an accurate, but expensive and time consuming method to evaluate the perceptual quality of 3D video. Chen et al. have defined the required steps to achieve a fair comparison between different 3DTV technologies [21]. It should be noted that the overall 3D QoE depends on multiple factors, some of which are independent of the coding and transmission aspects, such as the way the 3D video content is recorded and post-processed and displayed. The main goal of this section is to evaluate effects of scalable multi-viewpoint coding, packet losses, and adaptation strategies on the perceptual QoE.

3.1. 3D Perception of packet losses

Packet losses are inevitable in IP networks. In UDP a packet can simply be dropped due to best effort nature of the Internet and in TCP, data can still be considered as lost if it is delayed until play-out elapses and it becomes completely useless. So far, researches have mostly focused on perception of 3D video without packet losses, investigating different encoding options such as asymmetric rate allocation. Most of the studies reveal that human visual system (HVS) tends to neglect loss of high frequency components in one of the views [22][23]. However, the effect of packet losses/delays over visual perception of 3D video and whether HVS can compensate the artifacts generated by concealment methods has not been studied. Since lost data significantly affects the perception error concealment at the receiver side is an important issue for transmitting MVV over IP.

One important factor that can play a key role in this experiment is the implementation of error concealment algorithm. In this study, we have employed two different error concealment methods. In the first method slice level error concealment algorithm based on slice repetition is employed. When a slice of a frame is lost the corresponding region's residue is replaced from another frame that is closest in picture order count metric. This approach performs well for slices that has limited or no motion, but introduces distortions when there is a significant motion within the lost slice's region. The alternative method is frame repetition. When there are lost slices in a frame, previous lossless frame is replaced with that frame to avoid any mismatches between lost slice and remaining residue.

Second factor is the duration of error and whether it affects both views or not. Normally, due to bursty nature of packet losses over the IP [24], the errors that occur for a time interval, effects both views (See Fig. 2-a.) But it is possible to delay one of views or interleave its data in a way that different sections of the data are transmitted at a time instant (See Fig. 2-b). In this case longer interval of the video becomes erroneous but the errors are more likely to be separated over different intervals. We have investigated if HVS favors one of these cases.



a) Overlapping error interval   b) Separated error interval

Fig. 2: Loss intervals in stereoscopic 3D video

3.1.1. Test Content Preparation

We have encoded the contents enlisted in Table 1 using H.264/AVC with GOP size 16 frames. Then, the encoded bit streams are simulated to be sent over channels with %3 and %5 loss rates generated by trace files provided in [18]. In the first transmission methods, both streams are forwarded as is, whereas in the second method, the GOPs are interleaved to decrease the chance of having error in the same time interval for both views. Then received streams are decoded using either frame or slice based error concealment. In the end, we have total of 12 test sequences (3 contents, 2 types of transmission, 2 types of error concealment methods.) and 3 more sequences without any decoding errors.

Table 1: Source video sequences

Name	**Resolution**	**Information**
Adile	640x480	Computer
Flower	704x448	Moving camera
Train	704x576	Fixed camera

3.1.2. Subjective Tests and Results

Subjective tests are performed to evaluate the perception of above mentioned conditions in 3D. The testing methodology is based on the Double-Stimulus Continuous Quality-Scale (DSCQS) method [25]. We have tested with 7 male and 3 female assessors and 7 of those were experts in 3D video coding area. The display setup, and evaluation criteria can be found in a former study [22].

The results reveal that even though the error interval has been extended, people significantly prefer the second option. This is probably due to the features of HVS, as it may conceal the effect of packet loss up to a certain degree. This finding affects our P2P chunk scheduling scheme. Normally, we have both views streamed concurrently, exposing them to variations in network conditions. But now we interleave the views decreasing the effect of lost data segments. This approach is explained in Section 4. Moreover, people have preferred slice based error concealment method even in sequences with high motion (such sequences generate more disturbing mismatches in slice based error concealment methods compared to frame repetition.) More information about these tests can be found in our former study [22].

3.2. 3D Perception of view and depth adaptation

In the scope of medium term and long term 3DTV applications, depth maps seem to be a dominant part of the 3D video format delivered to homes. Depth maps play a major role in synthesizing high-accuracy intermediate views for multi-view and light-field displays, and generating better quality and variable baseline stereoscopic video pairs for conventional 3D displays. Nevertheless, the existence of more than two viewpoints, alongside with their depth components will necessitate view adaptation from time to time, especially when network congestions are observed. Missing views will either be discarded or interpolated using the existing viewpoints. To our best knowledge, there is not enough research in the literature that investigates adaptation through defining the color and depth priorities, as well as view scaling and quality scaling priorities, targeting the ultimate perception of resultant stereoscopic video.

We have performed a series of experiments to investigate the useful bandwidth adaptation approaches in the scope of depth based stereoscopic video format comprising two view-plus-depth pairs (referred to as MVD2 from onwards). MVD2 is encoded using SVC, using a single or two quality layers, based on a particular coding scheme. This scheme comprises asymmetric SVC for both color and depth components. The effectiveness of utilizing asymmetric coding in adapting stereoscopic video was formerly reported [26] for conventional stereoscopic 3D. In our scenario, one of the pairs is encoded with a single layer (reasonably high quality) and the other pair is encoded with two quality layers. In times of network congestion, the layered pair is scaled. Furthermore, two sub-adaptation scenarios are deployed within this coding scheme as follows:

1. Truncating the enhancement layer packets of each component equal wise and continuing to download both views and depth maps,
2. Truncating the view with its depth completely from the downloaded bit-stream and letting the decoder estimate the missing stereo pair by using DIBR from the downloaded high quality view-plus-depth.

In both sub-scenarios, the amount of truncated packets from the bit-stream is adjusted to be very close to each other for a fair comparison of different adaptation choices. We have used two test video sequences (Akko&Kayo @640x480, 30 fps and Newspaper@1024x768, 30fps) each having two cameras and two depth maps. Quality is assessed as the average PSNR of resultant left-right stereoscopic video seen. To be more perceptually precise, spatial Peak Signal-to-Perceived Noise Ratio (PSPNR) is also computed. The results we obtained are summarized in **Table 2**.

Table 2: Resultant stereoscopic video quality with different adaptation scenarios

	1st Adaptation Scenario		**2nd Adaptation Scenario**	
	PSNR	**S-PSPNR**	**PSNR**	**S-PSPNR**
***Akko&Kayo* (originally streamed at 1.8 Mbps)**	**33.9 dB (at 1.25 Mbps)**	**39.6 dB (at 1.25 Mbps)**	**34.7 dB (at 1.25 Mbps)**	**40.7 dB (at 1.25 Mbps)**
***Newspaper* (originall streamed at 2.2 Mbps)**	**32.4 dB (at 1.45 Mbps)**	**38.6 dB (at 1.45 Mbps)**	**32.7 dB (at 1.45 Mbps)**	**39.6 dB (at 1.45 dB)**

These indicative results, i.e. an average PSNR difference of 0.5 dB (and average S-PSPNR difference of around 1 dB) between both adaptation scenarios suggest us that at harsh network conditions, such as when the streamed 3D video needs bandwidth scaling to a large extent, view adaptation (second scenario) may offer a better stereoscopic viewing performance. One reason for this result is that the delivered pair of color and depth video at highest quality can lead the HVS and may hide the degrading effects of occlusion estimation in the estimated stereo pair. Nevertheless, when the fluctuations in the available transmission bandwidth are not as extensive as experimented in our case, the choice of adapting the quality of color and depth video streams would be sensible to not to neglect a complete view stream at the expense of losing occlusion information. It should also be noted that the choice of view adaptation and depth/color video quality adaptation should be done in accordance with the user viewing equipment, as stereoscopic rendered videos with large baseline (depending on the displayed screen size) may fail to perform well when estimating the occlusions. Hence, depth/color video quality scaling may become more feasible. Further investigation in this regard is needed to formulize the adaptation approach depending on the use cases.

4. Adaptive MVV Streaming over P2P Networks

For multimedia transmission over the Internet a cross layer design should be adopted in which application and network layers are working in harmony to deliver the highest possible quality with the available resources. For 3D multimedia transmission, design should also consider the perception of 3D media and perform adaptation decisions accordingly to provide highest QoE. In our proposition, the application is network aware, as it creates chunks considering the characteristics of networking layer transport protocol. In Section 4.1, we present proposed video coding and chunk generation methods. Similarly, networking layer operates in a content-aware manner as it prioritizes streams that are more critical in the case of congestion. Section 4.2 presents window based adaptive streaming/scheduling algorithm that respects both the video coding concerns and the perception of 3D video prone to IP errors. Following subsections provide information on additional features and system parameters, which we determine based on experiments over controlled LAN environment (See Section 5).

4.1. Generation of Chunks for Adaptive P2P Streaming

Chunk generation for MVV Streaming P2P framework is performed in two steps. First, the video is encoded using one of the techniques presented in Section 2, and then the output stream is split to chunks. We have employed simulcast coding technique using SVC for the following three reasons: **i)** SVC is the only option (currently available) with SNR scalability, which provides high adaptation capability with relatively low overhead. **ii)** With simulcast approach, the receiving node does not have to consider inter-view dependencies, easing the streaming procedure in P2P environment where it may be more difficult to discover and receive dependent streams within time limits **iii)** Although in theory MVC may provide better encoding efficiency, we are aiming displays that have high number of views such as 10 to 50. The best method of coding to deliver such large content is to use multi-view + depth-map representation, in which camera locations are separated significantly and artificial views are generated at the receiver side using depth information. In such recoding conditions, MVC offers marginal gain in compression efficiency.

Packetization of multimedia content considering the underlying network infrastructure has a critical impact over the performance of any streaming solution [27]. For a Torrent based P2P system, packetization corresponds to formation of chunks. We propose a method using the SVC encoded bitstream and splitting that stream at group of pictures (GOP) boundaries so that each received chunk can be decoded, because each GOP starts with an intra-coded frame (I-frame) (See Fig. 3). The SVC stream starts with header NAL Units consisting of Supplementary Enhancement Information (SEI), Sequence Parameter Set (SPS) and, Picture Parameter Set (PPS). The headers provide vital information such as picture resolution in macroblocks (MB) and decoded picture buffer size. We propose to provide headers NAL units in metadata file so a user may test whether the content is suitable for its terminal or not prior to streaming process. Moreover, by this way, metadata NAL units are not affected by loss or delay events that could make rest of the stream useless. The header information is followed by NAL units of video frames. When slice mode is disabled there is one base layer NAL unit and one enhancement layer NAL unit for each frame. If the enhancement layer is lost, the remaining stream is still useful in generating frames but at a lower quality, indicating that enhancement layer NAL units are discardable. Therefore, we split base and enhancement NAL units into separate chunks (See Fig. 3.) Please note that, due to the syntax of SVC, only the first GOP has two I-frames (represented with *) creating a relatively larger chunk size.

Likewise, the encoding scheme is very important. When only hierarchical B-frames are utilized to obtain the best encoding efficiency, the chunks become dependent on each other as they share I-frames. Therefore, the coding scheme should make each chunk independently decodable and avoid any inter-chunk dependency to obtain the highest performance in video transmission over lossy IP channel.

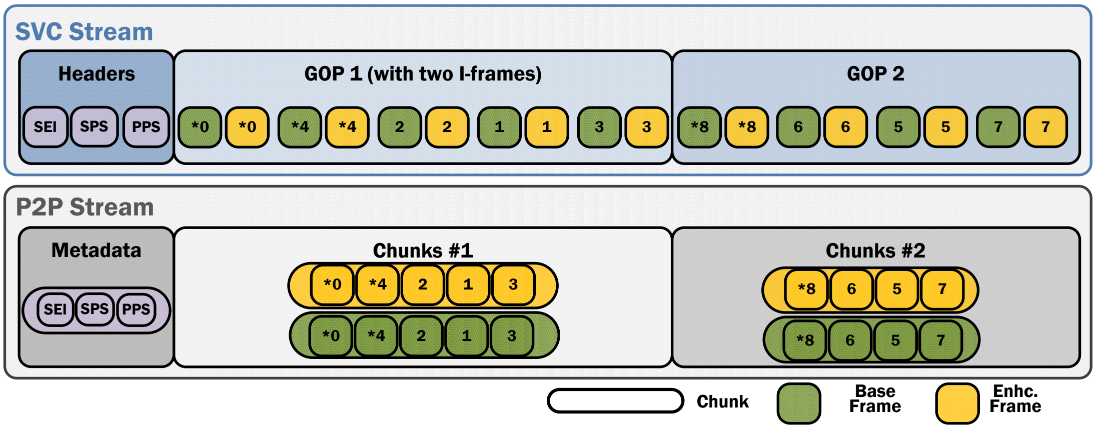


Fig. 3: Chunk generation using one GOP per chunk (GOP size is 4 frames)

4.2. Chunk based adaptive Multi-view P2P streaming

4.2.1. Quality Adaptation and chunk scheduling

The windowing mechanism in our framework is extended of the one defined in Section 2.3 (See Fig. 1) in two additional dimensions. The first dimension is number of views meaning that there are separate windows for each view and depth-map. The second dimension is to represent the importance level (discardibility) of the chunks to enable adaptive streaming as depicted in Fig. 4. In our model, all base layer chunks must be requested prior to enhancement layer chunks. With this approach, the scheduling mechanism tries to ensure smooth video playback and high quality when possible.

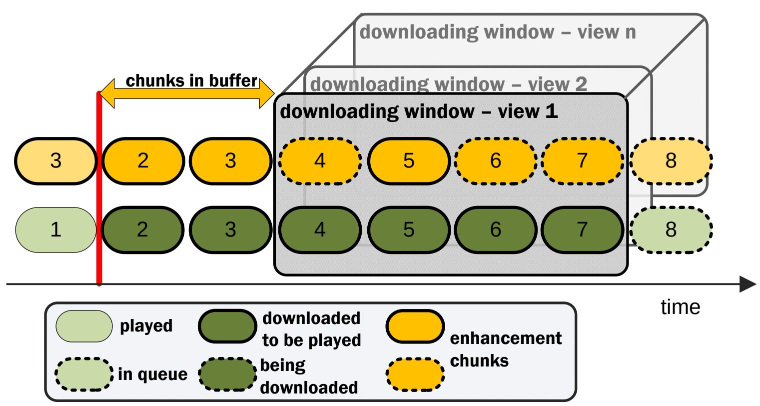


Fig. 4: Downloading window with two layers
(The red line indicates current location of the player.)

Using the visual test results Section 3, we state that if one of the adjacent views has slice or packet loss then it is possible. This result can be exploited in the following way. When choosing chunks that are going to be downloaded for adjacent views, it is best to choose them for different time instances because if a chunk is lost (in UDP) or delayed (in TCP) then it may be possible to conceal it using adjacent view to a certain extend. In the other case (when equal time instances are requested for each view), if the available bitrate is low, then it is more likely to experience packet losses in all view, making artifacts more perceivable.

4.2.2. View Adaptation

Different from the bandwidth adaptation in conventional video systems, adaptation in the scope of multi-view 3D systems comprises depth adaptation and viewpoint adaptation. The other prominent adaptation tool is quality adaptation that allows graceful degradation in the perceived video quality, while allowing the adaptation of bandwidth in a broad range. Viewpoint adaptation refers to truncating the packets of particular viewpoints from the delivered bit-stream and either allowing the missing viewpoints be estimated (interpolated) from the delivered viewpoints or not displaying them at all. Within Free-Viewpoint Video (FVV) [28] applications, where the user(s) would only be interested in a particular section of the overall 3D scene, only a single viewpoint or a sub-set of viewpoints would be delivered. On the other hand, multi-view applications, which necessitate reconstruction of a complete 3D scene all times, the view adaptation as a result of bandwidth shortage would necessitate the interpolation of the missing views. The latter one actually refers to bandwidth adaptation by utilizing view adaptation. This fact reminds us that there should be a strategy for deciding which viewpoints should go to which scalability layer, in order to maximize the chances of reconstructing the 3D scenes at optimum quality in dynamic bandwidth conditions. Depth adaptation refers to trading the bandwidth spent for delivering depth maps for the sake of either reducing overall required bandwidth or, by allocating more bandwidth to the color view component increasing the texture quality. However, knowing that the perception of depth is also affected by the depth component, this trade needs careful decision taking as in the case of view adaptation. Furthermore, the geometrical consistency of the video objects in the interpolated views also depends on the quality of the depth maps. Depth adaptation can be achieved in two ways: by completely ignoring the depth component and blocking view synthesis (e.g. only the base representation in the form of either 2D, stereoscopic or baseline adjusted multi-view is used), or by deploying quality scalability in depth component in accordance with the corresponding color video component to allow graceful bandwidth adaptation.

Depending on the level of the dedicated QoE for the 3D video service, which not only depends on the delivered content or the network state, but also to the user and display requirements, and depending on the dynamic network character, a generic multi-view rate adaptation strategy should target consistent viewing experience without much fluctuation in both the texture quality and depth perception. The reason is that, unlike in 2D viewing, in 3D viewing, the users cannot adapt their vision to quickly changing states of a scene. This is partly overcome by carefully organizing and recording the 3D scene. In our work, the rate adaptation as a combination of view adaptation, depth adaptation and quality adaptation per camera should be formulated to achieve this target. Previous research work by Petrovic, et. al., has proposed an adaptive 3D video streaming scheme over the internet, by maintaining the average stereoscopic video quality without utilizing scalable video coding [29]. Scalability in our work will make the adaptation task proceed faster (without a need for transcoding) and be more graceful, while allowing dynamic rate allocation between camera views and between color and depth components. Since view adaptation is a more prominent adaptation type in truly multi-view applications (e.g. multi-view broadcasted events in medium term), but not in modern 3DTV systems that are based on stereoscopic video, this research work is primarily focused on rate adaptation through quality and depth adaptation, considering the overall QoE (temporal and spatial aspects together) all times.

4.3. System Parameters

4.3.1. Chunk Length

It is possible to pack single frame as a chunk but in that case there would be high control message traffics because each received chunk is announced to neighboring peers to indicate its availability. On the other hand, too long chunks decrease the adaptation capability. Then the question is what should be the size of the chunks. In Section 5.2 we have provided an answer to this question based on the TCPs performance over delayed networks.

4.3.2. Window Size

P2P solutions can be used to levitate the bandwidth scarcity problem in server-client model services (See Fig. 5). In our proposed framework, this problem is addressed as follows; upon successful downloading a chunk, each peer notifies its neighbors to indicate its availability. And when a peer is going to download a chunk, it checks if it is available within the swarm. A request from server is done only if there are no neighboring peers that have the requested chunk. By this way, the bandwidth requirement of the server is significantly reduced. The size of the download window has a critical impact upon the workload of the server. This relationship has been investigated in Section 5.3.

There may also be a case that the requested chunk is available within the swarm but peer may not have that node in its list, since the tracker provides only a sub-list of peers. In that case, when the peer makes a request from the server, the server may reply with a redirection message instead of the actual data. A request from server is done using HTTP protocol, in which server replies either with message code 200 (OK) or redirection (302). Using an open-standard protocol has its benefits that are discussed by Gurler et al. [30]. Naturally, in order to track the content within each peer, the server side has an authentication mechanism, which is also helpful in providing copyright management issues.

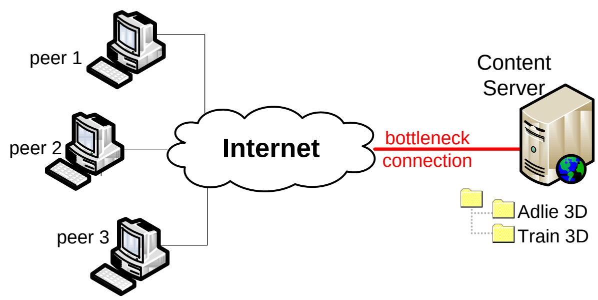


Fig. 5: The bottleneck connection for server side

4.4. Half Delivered Chunks

During the transmission, it is possible that a chunk is only partially delivered. If UDP is the network protocol, this can be simply because a packet is lost and the system did not have enough time to retransmit it. In the case of TCP, the presentation time for that particular chunk may be elapsed. Nevertheless, if a chunk is partially received it may still be used to yield as much frame as possible. One important consideration is the security aspect because it is not possible to have integrity check for half received chunks using hash values. One possible solution is to include hash values for each frame. However, this approach significantly increases the size of metadata file.

5. Experimental Results

5.1. Test Environment

All network tests are performed in controlled local area network (LAN) environment. In order to adjust link capacities, we have used NetEm library of the Linux kernel that can emulate different channel conditions by changing bandwidth capacity, packet loss rate and round trip time [31]. Similarly, bandwidth tests are performed using iperf tool, which is well respected and very accurate network analyzer [32].

5.2. Determining size of video chunks

In this experiment, we try to optimize the chunk size according the characteristics of TCP. The size of the video chunk is a critical parameter can affect the overall performance of the system. Choosing it too short or too long affects the adaptation capability and transmission efficiency. We believe that TCP is the dominant protocol over the Internet, not because it has the most suitable features multimedia applications but its connection oriented transmission enables bypassing through firewalls and makes it friendly to network address translators (NAT). Since most of the ADSL modems require *port forwarding* to deliver UDP packets and who people are behind NATs and firewalls and almost unable to receive UDP traffic at all, it is natural to think that TCP dominates the P2P architectures.

The drawback of TCP is that it has a slow-start nature by design. Sender has to wait for successful acknowledgements before incrementing size of its output buffer. Naturally, this takes some time and if the transmission occurs in a shorter interval, then TCP cannot fully utilize the link capacity. Fig. 6 depicts the TCPs average throughput for channels with varying capacity and delays. These figures reveal that TCP may utilize a channel within the first second for one way delay up to 100ms (200ms for RTT). This result indicates that, a protocol that transmits data less than 1 second may have result in underutilization of the network. Therefore, we conclude that the number of GOPs per chunk should be set such that it includes a duration of 1 second.

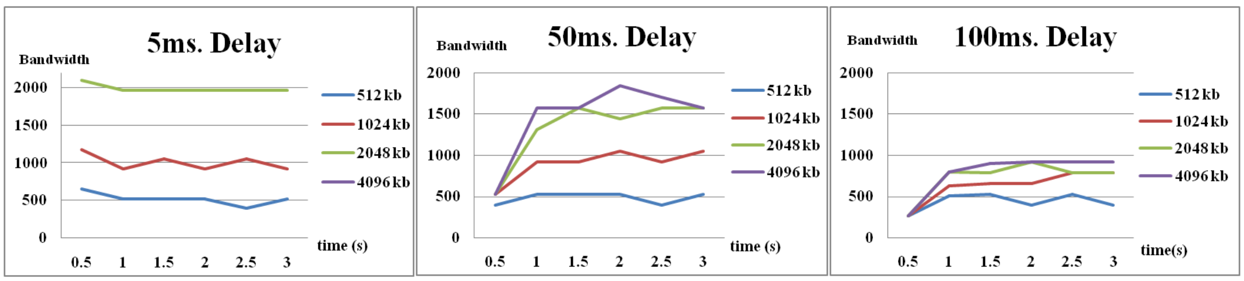


Fig. 6: Averaged TCP throughput over time for different channel conditions

5.3. Determining size of downloading window

The size of the downloading window has an effect on two important system features, one explicit and one implicit. The explicit one is the pre-buffering delay. Longer window size requires higher pre-buffering delay because chunks within the windows are streamed in random order and needs to be completed before sequential playback. Secondly, the window size affects workload on the server side. If the window size is long there is a higher chance that peers will request different chunks from the server, allowing more chunks to be exchanged among peers. In one extreme case, window size is being equal to one. Then the peers with similar bandwidth capacity will have the similar chunks since they download in the same order. Naturally, such peers will have significantly less chance to get a unique data to exchange among each other. Consequently, most of the chunks will be requested from the server, increasing the workload on the server.

We have performed networking tests with a single band-limited server and multiple peers. The test is performed for 1000kbps, 2000kbps, and 3000kbps rates with peers from 2 to 4. We assume that the server side has a limited bandwidth capability and the peers have to exchange data among themselves to avoid congestion as much as possible. The test duration is 1000 chunks (~1000 seconds) composed of 2 GOPs each with 16 frames.

The test results, presented Table 3, clearly indicate that the longer window size allows higher sharing rate among peers. In each cell, the numbers present the average percentage of chunks received from both server and P2P, whereas the number in parenthesis is the percentage of chunks received only via P2P network. Naturally, increase in the number of peers increases server bandwidth requirement. If the bandwidth requirement is above the link capacity then peers starve and experience lost base layer chunks. However, if the window size is large enough than additional peers can be compensated meaning that bandwidth cost of the peers can be reduced by increasing the pre-buffering time. Moreover, the adaptation policy is successful in the sense that peer prioritize the base layer chunks when the bandwidth is limited. The increase in window size also augments the reception of enhancement layers because increase P2P activity allows additional data to be transmitted from the server side.

Table 3: Peers average percentage download statistics with different window size and bottleneck link capacity. Each cell: Total received (received only via P2P network) chunks in percentage

	Bottle Neck: 1000 kbps		Bottle Neck: 2000 kbps		Bottle Neck: 3000 kbps	
	Base	Enhancement	Base	Enhancement	Base	Enhancement
# peers	Window size = 1		Window size = 1		Window size = 1	
2	96.4 (3.3)	7.6 (1.3)	100 (33.2)	97 (33.1)	100 (37.2)	100 (0)
3	63.3 (1.7)	5 (0.0)	96.9 (34.1)	68.9 (13.9)	99.8 (12.2)	87.3 (10)
4	55.7 (14.6)	8.9 (0.4)	87.6 (23.0)	31.1 (4.1)	95.7 (32.4)	70.2 (11.7)
	Window size = 2		Window size = 2		Window size = 2	
2	95.2 (9.8)	14.1 (1.4)	100 (32.2)	100 (34.1)	100 (40.3)	100 (37.9)
3	66.4 (6.8)	6 (0.2)	98.9 (40)	81.8 (25)	99.5 (54.6)	99.3 (54.4)
4	54.6 (14.6)	10 (0.4)	88.3 (32.7)	36.9 (18.0)	96.0 (42.4)	71.2 (13.8)
	Window size = 4		Window size = 4		Window size = 4	
2	95.9 (29.9)	35.5 (4.5)	100 (38.1)	100 (38.15)	100 (41.3)	100(41.2)
3	75.7 (26.0)	16.7 (2.1)	99.1 (60.6)	95.2 (57.2)	99.8 (57.9)	99.5 (56.9)
4	65.8 (29.0)	13.9 (1.6)	94.0 (54.3)	65.9 (20.6)	96.4 (39.1)	72.6 (17.2)
	Window size = 8		Window size = 8		Window size = 8	
2	97.1 (39.0)	45.5 (7.0)	100 (45.6)	100 (45.2)	100 (45.6)	100 (45.8)
3	83.3 (43.2)	29 (6.6)	99.9 (60.23)	99.4 (59.7)	99.9 (60)	99.6 (57.9)
4	69.5 (32.2)	14.4 (5.0)	96.6 (59.4)	69.0 (26.8)	95.8 (38.2)	73.2 (18.5)

6. Conclusions

IP offers flexible channel capacity to delivery MVV which has varying bitrate requirement based on the number of views transmitted. In order to provide a more scalable delivery in terms of increasing number of users, we propose a P2P streaming solution based on successful file sharing protocol, Bittorrent. We extend the Bitttorent approach with a windowing mechanism to enable both adaptive streaming and control the workload of the server side. We have also identified the effect of system parameters such as chunk and window size. We have shown that increasing the window size augments the video quality but introduces pre-buffering delay which indicates a trade-off.

A solution over IP should consider characteristics of the networking protocol to achieve the highest throughput. In this sense, our proposed solution is cross-layer architecture in which application and transport layers work in harmony to provide the best perceived quality. In short, the application layer generates discardable chunks so that the transport layer may omit them in the case of bandwidth scarcity. Moreover, the application layer generates the chunks at a size that minimize side effects of using TCP such as slow start. The proposed solution also regards perception of 3D video by HVS which suggest a new type of scalability option, view-scalability. We provide tests regarding perception of 3D video in the case of packet loss and propose a new scheduling algorithm to increase the QoE.

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