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Media-aware Networking for SVC-based P2P Streaming

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ABSTRACT

There are currently two concurrent trends in the Internet. First, the number of Internet users and their connection speeds are increasing rapidly. Second, Internet-based applications are dominating how people receive information, communicate, and entertain themselves. Therefore, we are witnessing an enormous increase in IP-based multimedia traffic, which is putting an enormous strain on the network. Additionally, router and network virtualization are gaining importance, enabling more intelligent networks. Therefore, we argue that networks should not be merely bystanders to this multimedia revolution. In this paper we present a media-aware network solution based on router virtualization that aims at striking a balance between intelligence and adaptation at the edge and in the core of the network. Using an extensive simulative study, we demonstrate that our media-aware network not only helps in enhancing streaming performance during bottlenecks, but also minimizes the side effects of congestions on user perceived quality, making it a need for future Internet multimedia applications.

Categories and Subject Descriptors

C.2 [**Computer-Communication Networks**]: Distributed Systems

General Terms

Algorithms, Design, Performance

Keywords

Media Awareness, Router Virtualization, Scalable Video Coding, Peer-to-Peer, Multimedia Distribution, Streaming.

1. INTRODUCTION

The increasing number of Internet users and their connection speeds along with the domination of Internet-based applications have created an enormous increase in IP-based multimedia applications and traffic. The challenge of transmitting multimedia data is due to its strict requirements on bandwidth, where more strain is put on the network. To aggravate this, video content is constantly gaining more quality and posing higher requirements on the required bandwidth. We have seen the rise of high definition content that requires more than 2 Mbps throughput, and, with the introduction of 3D and multi-view video, bit-rates are expected to explode.

Client/Server systems alone cannot cope with this steep increase in required bit-rates. Therefore, peer-assisted video streaming systems are becoming more attractive [8, 11]. In such systems, peers that have downloaded some content can assist servers in re-distributing it. This paradigm, therefore, allows streaming an increasing amount of multimedia content (with high bit-rates) to an increasing number of users. This shift in paradigm, however, inflicts a shift in the distribution bottleneck from the server side to the network core [3], since peers with high speed access act as micro video servers. This raises many questions: *are classical routing elements enough to cope with this shift? how can we implement efficient yet simple media-aware solutions?*

We argue that next generation multimedia applications must take this pressure on the network core into consideration. Since rolling out new high capacity links would inflict high costs for network providers, intelligent network elements become necessary to manage the enormous multimedia traffic. While the growth of multimedia traffic increases the load on the network, media awareness would help in alleviating its effects especially during congestions. Although streaming applications can use intelligent techniques at the *edge* of the network, they have no control in the core.

In this paper we present a media-aware network solution, which can be gradually introduced into the core network. Our solution helps to increase the perceived Quality of Service (QoS)[1] during congestions that arise in high quality P2P streaming systems. We make use of router virtualization to enable application-layer congestion control that can be activated on-demand. Additionally, the content provider can define how the virtual routers should handle the P2P streaming traffic upon a congestion. Therefore, we propose

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[1] Perceived QoS constitutes a set of measurable metrics that reflect the user experience. These, as presented later, include session and video quality. QoS and perceived QoS will be used interchangeably throughout this paper.

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that content providers use media-aware solutions that are specific to their applications.

In this paper, we design and evaluate a media-aware network solution for P2P streaming systems that are based on Scalable Video Coding (SVC). We show that media awareness can improve QoS and that even a basic intelligence inflicts substantial performance benefits.

The contributions of this paper are as follows: (1) we present a simple yet effective approach to implement media awareness using router virtualization techniques, (2) we analyze the impact of media awareness on various metrics that reflect the perceived video quality, (3) we show that even with minimal intelligence in the core, performance of SVC-based P2P streaming systems can be enhanced.

This paper is organized as follows. In Section 2, we give an overview on background and related work. The media-aware network solution is presented in Section 3. We present our evaluation methodology and results in Section 4 and finally conclude the paper in Section 5.

2. BACKGROUND AND RELATED WORK

Research on media awareness has been an active topic in the research community for some time [7, 6]. The aim is to find efficient methods to achieve a smooth and high quality playback. Approaches related to ours can be broadly summarized as solutions that utilize information on the importance of different media parts to either enhance the quality or limit video distortion. This utilization can either be done at the edge [9, 7] or the core of the network [6]. Solutions at the edge, on one hand, usually implement media awareness through overlay routing and media-aware scheduling. Further, there exist many solutions that fall into the distortion-aware media drop category [7, 12]. Upon congestions, such methods would drop media packets according to the distortion that would be inflicted on the video quality.

Solutions in the core, on the other hand, try to utilize QoS management capabilities available at network routing elements. In [6], Fidler shows how Differentiated Services [10] can be used to improve system performance when using layered video coding. Our solution differs since we systematically assess the priority of SVC streams and show that this priority consists of temporal and quality aspects. We further take a new approach, namely using router virtualization, to implement media awareness. We show that a simple media-aware network solution for SVC-based streaming systems can greatly enhance the perceived QoS.

SVC is the extension of the H.264 Advanced Video Coding (AVC) standard that offers encoding a video file with three dimensions of scalability. While the video has to be encoded only once, receivers can retrieve and play only certain subparts of the global stream. Therefore, different receivers can play-out the video stream with different resolutions (spatial scalability), frame-rates (temporal scalability), and picture quantization levels (quality scalability). SVC video streams are composed of two classes of video blocks, a base layer and further enhancement layers. The base layer is always needed for decoding the video file. With more enhancement layers available, a better quality can be achieved. However, when the base layer is missing, playback is not possible. This is known as stalling or playback freeze. SVC enables the support for heterogenous devices and quality adaptation. For example, a mobile device and a desktop machine can both receive the same video stream but with different resolutions.

Much research has been done on building P2P streaming systems that use SVC [1, 5, 2]. SVC is used in those solutions to adapt the streamed quality according to various resources available at the end devices. Therefore, we believe that such a video coding standard will become very important in the future. Thereby, it is essential that the networks are aware how such videos are structured to better manage and allocate resources.

3. MEDIA-AWARE NETWORK SOLUTION

Future Internet networks should be able to better react to congestion of multimedia traffic by taking into account the importance of different video packets. For streaming applications in general, it is very important to have prioritized traffic management to achieve QoS. When classical routers get congested, they usually drop packets that might be more important than others, i.e. in a media-agnostic fashion. But the question remains, how can we add more intelligence to routers for better congestion control?

Our approach is based on harnessing the power of router virtualization to enable advanced traffic management along with application layer control. Router virtualization is based on the idea of running multiple software routers on a single hardware router. The different software routers can have different roles and be activated and even migrated on demand. Recently, efficient implementations for router virtualization have been proposed where full network speeds can be achieved by combining a fast forwarding plane (e.g. OpenFlow[2]) with software routers [4].

Our network model and scenario are shown in Figure 1. There, routers connect different subnets and forward data from and to several end users. In a P2P streaming system, edge routers' upload utilization will generally become higher, since data would be flowing from end users to the core network [3]. This issue becomes especially evident when streaming video content with high quality.

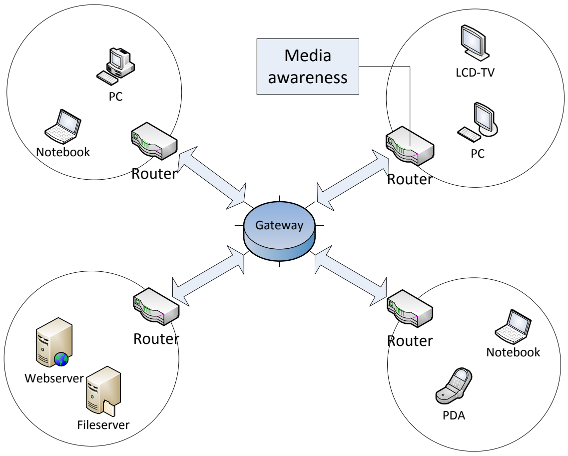

Figure 1: Media-aware network scenario

3.1 Router Virtualization Versus Classical QoS

Before detailing our architecture, we first stress the need for including router virtualization rather than classical QoS

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[2] http://www.openflow.org

techniques. Using router virtualization, it is possible to have QoS at the application layer, therefore, enabling optimization in the direction of perceived QoS. Additionally, efficient and custom-made QoS solutions can be developed and used as needed. For example, different virtual routers can be deployed for live and on-demand streaming, since both use different techniques for media awareness.

Another advantage of router virtualization is that it enables the gradual development of media-aware solutions and protocols, which is not possible with classical approaches. Additionally, a virtualized router does not have to be running all the time as it can be executed only on-demand when bottlenecks occur, exactly at the point when performance and perceived quality would degrade. Nonetheless, one can still argue that prominent QoS management techniques such as Differentiated Services [10] can achieve similar goals. But the main issue there is that using the Type-of-Service bits, only limited priority information can be communicated with the router. Additionally, QoS can only be controlled by the network provider and not the content provider. Since the latter has a better idea about its users' access patterns, content popularity, and the scheduling of its own traffic, a router virtualization solution enables the implementation of more sophisticated management algorithms. Therefore, a solution similar to the one presented in this paper allows for homogenous QoS handling of multimedia traffic across different networks. Additionally, the content provider, based on some business model with the network operator, can deploy its own policies and algorithms to implement custom-made media-aware solutions.

3.2 P2P Streaming System

The media-aware solution presented in this paper is designed for a quality-adaptive P2P video streaming system that uses Scalable Video Coding (SVC) [1]. Here we give an overview on the core mechanisms of the system required to understand the contribution of this paper.

In this system, the content provider is interested in using P2P techniques to reduce its costs, but still has to deploy servers that would sustain QoS for the users. Such hybrid scenarios have shown to have highest potential in realistic scenarios [8, 11]. A tracker is used to coordinate all peers within the system and keeps track for each peer, its online status, selected video stream, and streamed layer. To enable multi-source download, the global SVC stream is divided into multiple parts called *pieces*. A piece constitutes a playback unit, usually ranging between 0.5 and 2 seconds. Each piece in turn is divided into multiple SVC blocks. Receiving more SVC blocks in the different SVC dimensions, leads to higher quality in the respective dimension.

During runtime, each peer performs local *quality adaptation* of the requested video quality according to various parameters of the device and the network. Therefore, the received quality can be adjusted according to static peer resources, as well as to the dynamic network status. When a streaming session is initiated, an assessment of static local resources has to be performed. This, as presented in [1], is called Initial Quality Adaptation (IQA). The IQA mechanism helps in matching requested video quality to local resources already from the beginning by taking into account the static peer resources: screen resolution, available bandwidth, and processing power. After streaming has started, a control loop has to make sure that playback remains smooth. The module responsible for this is called *Progressive Quality Adaptation* (PQA). In addition to taking into account the static resources as for the IQA, the PQA additionally adapts to the dynamics of the system reflected through the active throughput and SVC layer availability. The PQA has to be performed periodically, and, therefore, defines the speed of adaptation. As presented in [1], having a smaller adaptation interval helps in quickly reacting to network changes and, therefore, playback is more smooth. Nonetheless, this comes at the expense of settling for lower SVC video quality.

3.3 Calculating Priority of SVC Streams

Every SVC video block has a certain temporal and quality priority, denoted by P_T and P_Q respectively. The temporal priority generally expresses how soon a certain video block is needed. Video blocks, which are closer to the current playback position, have a higher temporal priority than others. Suppose a certain receiver peer p_r with playback position B_{play} is requesting a block with index B_i from a sender peer p_s. The temporal priority of the block, as reported by p_s, is $-(B_i - B_{play})$. This priority is, therefore, higher when the requested block is closer to the playback position. We normalize this priority by the buffer size S to get:

$$P_T = -(B_i - B_{play})/S. \tag{1}$$

The quality priority, on the other hand, reflects the important of the SVC enhancement layers. Using it, lower layers for the video stream are given higher priority. For example, without the base layer, the video cannot be decoded. Therefore, the base layer is given the highest priority. The quality priority is calculated as:

$$P_Q = -(W_d\, d + W_t t + W_q q), \tag{2}$$

where d, t, and q denote the spatial, temporal and quality layers respectively (see Section 4.1). W_d, W_t, and W_q are used to weight the different scalability dimensions. This equation gives the base layer with $(d, t, q) = (0, 0, 0)$ the highest priority (0), while higher layers get a lower priority.

The temporal and quality priorities are included with every request. When a peer decides to serve a certain requested block, the respective priorities are reported along with the actual transmission.

3.4 Media-aware Virtual Router

We now present our approach for achieving media awareness in an SVC-based P2P streaming system. The goal here is not to present a complex prioritization algorithm, but rather to demonstrate how media awareness can be introduced into an SVC-based P2P streaming system. During bottlenecks, the virtual router prioritizes and controls block transfers based on priority information that reflect the perceived QoS or even policies that would depend on other network parameters as required by the content provider, for example content popularity. The main task of the virtual router is to prioritize block transfers. A video block is a video part as defined by our SVC-based P2P streaming protocol. The size of a block usually ranges from 16KB up to 2MB. The virtual router can retrieve the priority information for each block either using a separate communication channel or using deep packet inspection. To minimize processing overhead, only a single decision has to be made for all packets belonging to the same block. This greatly enhances scalability of the application layer processing algorithms.

The virtual router keeps a list of active transfers or connections that represent the blocks currently being uploaded along with their priorities. When there is a new incoming block, the router first retrieves the temporal (P_T) and quality (P_Q) priorities as defined above and adds this block to the list of outgoing transfers. When the virtual router is getting overloaded, congestion control is performed by using the priority algorithm to decide whether to forward, slow down or even drop some of the outgoing transfers. For actual priority calculation, we use exponential compensation to exaggerate the importance of blocks very close to the playback position or base layers. Therefore, the virtual router calculates a single priority for each block transfer by combining the temporal and quality aspects. This priority P is defined as:

$$P = T\,e^{P_T} + Q\,e^{P_Q} = Te^{-\frac{B_i - B_{play}}{S}} + Q\,e^{-(W_d d + W_t t + W_q q)} \tag{3}$$

where T and Q denote the weights for the temporal and quality aspects respectively, with $T + Q = 1$. Therefore, the priority as calculated above ranges between 1 (highest) to 0 (lowest). As next we evaluate the media-aware solution with different temporal and quality weighting factors.

4. EVALUATION

The described streaming system and the media-aware network were implemented in an event-based simulator. The reference approaches are a media agnostic network and a network that uses DiffServ. The media agnostic network applies classical congestion control and random packet drop. As for the DiffServ network, all packets of urgent blocks (within 7 seconds after playback position) are given a high priority service class. The DiffServ router prioritizes those blocks based on a first come first served policy.

4.1 Setup

We consider a typical Video-on-Demand (VoD) scenario with 90 peers actively participating in the streaming overlay. The peers are distributed over 4 subnets as depicted in Figure 1. All traffic leaving a subnet go through the router that performs media awareness upon congestions.

To ensure a minimum level of QoS, the content provider deploys servers that act as content seeds. We assume having 2 of these servers per subnet[3], with an upload bandwidth of 3 Mbps each. Peer resources are configured in a way to reflect heterogeneity. Therefore, peers are divided into 3 sets with different screen resolutions, namely: 176x144, 352x288, and 704x576. The bandwidth of the three sets is distributed as follows (upload/download): 128/256, 320/560, and 800/1200 Kbps, similar to [8]. Peers of the three sets are equally distributed over the four subnets of our network model.

We consider a 5 minute SVC video file with a total of 12 layers and a full bit rate of 1 Mbps. There are 3 resolutions (176x144, 352x288, and 704x576) and 4 frame-rate values (3.75, 7.5, 15 and 30 fps), resulting in $4 \cdot 3 = 12$ layers. For calculating the priority according to Equation 3 we choose an un-biased weighting: $W_d = W_t = W_q = 0.33\bar{3}$.

To assess the impact of media awareness as well as find the best router configuration we consider the following scenario: after streaming starts and peers start joining, we leave the system for 10 minutes to warm up. Then, we invoke an upload bottleneck of 3 Mbps for 10 minutes. This means that, during the 10 minutes, the router can only upload at 3 Mbps. Such a bottleneck can be due to limited resources allocated for this specific video stream or due to cross traffic. For comparison, we run the system with media agnostic and DiffServ routers as explained above.

4.2 Metrics

We divide the metrics in use into two categories: *session quality* reflecting playback smoothness and *video quality* quantifying the achieved video quality as described below.

4.2.1 Session Quality Metrics

Session quality metrics are:

- *Average number of stalls*: that represents the number of stalling events during playback. Stalling is an event, where playback stops due to missing required video blocks.
- *Average duration of stalls*: that represents the time till the playback continues after a stall event has occurred.
- *Average total playback delay*: that combines the two metrics above by representing the total stalling time per peer.

In general, the fewer and shorter the stalling events and delay, the smoother playback becomes, and the better is the session quality of our system.

4.2.2 Video Quality Metrics

Video quality metrics are:

- *Average number of layer changes.* A high number of layer changes means that the received video quality has to be adapted to the current status very often. For example, the layer is changed when stalling events occur, or when the needed quality is not available at the other peers. The lower the value of this metric, the better is the video quality. This is due to the fact that users can get quite disgruntled by too frequent layer changes [13].
- *Average relative received layer.* Each video piece is received in a specific video quality. The maximal possible quality, as calculated by the IQA, depends on the static peer resources. Therefore we calculate the average received layer throughout the streaming session and normalize it with the initial layer selected by the IQA. This metric represents how well the peer was able to sustain the maximal quality it can support.

4.3 Experiment 1: Impact of Media-awareness

In this experiment we want to assess the impact of our media-aware network as well as find the best configurations. We test the virtual router for a bottleneck of 3 Mbps and with different T and Q values, namely: T100, T70/Q30, T50/Q50, T30/Q70, Q100. For this experiment, the PQA interval was fixed at 10 seconds, which represents a moderate value [1]. We focus on the performance during the bottleneck as then performance degradation takes place.

Session Quality. We first present in Figure 2 the session quality during the 10 minute bottleneck period. There we see the average number of stalls, average stall duration, and the total stalling duration, all calculated per peer.

Starting with Figure 2(a) and comparing the media agnostic with our media-aware system, we can see that the average number of stalling events per peer is reduced from 1.15

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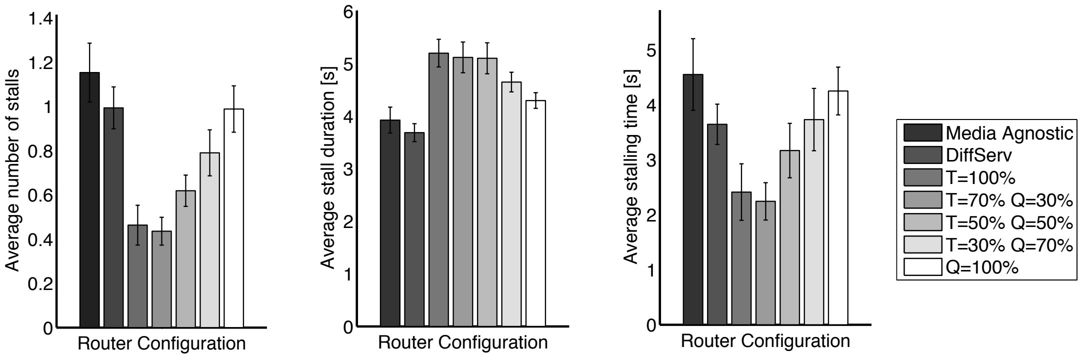
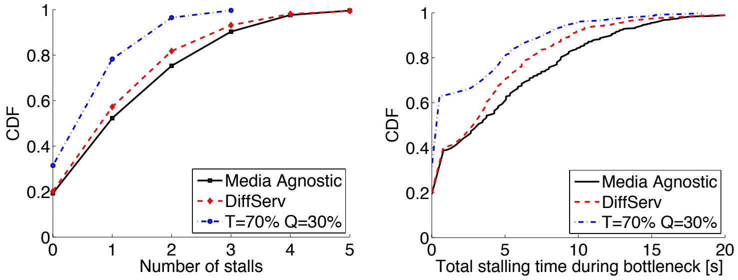
[3] We tested the system with different number of servers and achieved consistent results.



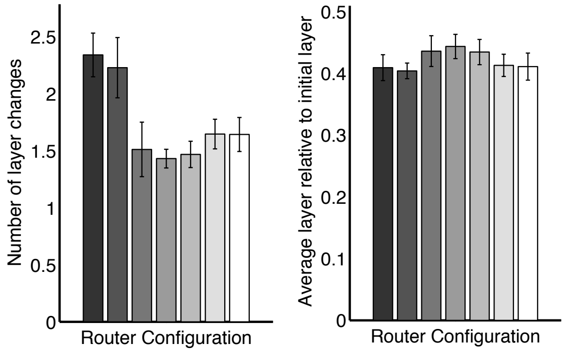
(a) Average number of stalls per peer (b) Average stall duration (c) Average total stalling time per peer

Figure 2: Session quality during bottleneck



(a) CDF of number of stalls (b) CDF of total stalling time

Figure 3: CDF of session quality during bottleneck



(a) Layer changes per peer (b) Average layer per peer

Figure 4: Video quality during bottleneck

down to 0.44. Although media awareness slightly increased the duration of stalling events (Figure 2(b)), it reduced the total stalling duration during the bottleneck as depicted in Figure 2(c). That is, the total stalling duration is reduced from 4.6 down to 2.2 seconds per peer, resulting in 52% less stalling. Although DiffServ performed better than a media-agnostic network, it was still not able to compete with a full-pfledged media-aware solution.

Examining the different configurations of the virtual router, we can see that the best results were achieved with T70/Q30, where we just have 2.2 seconds of total stalling during the bottleneck. This can be explained by the fact that a larger T means that sooner needed video blocks, especially in the buffer zone, are sent faster. It was still nevertheless important to include the SVC quality dimension with $Q = 0.3$ to make sure that peers do not have to wait long for SVC layers they have already requested. Figures 3(a) and 3(b) present the results as a CDF. These graphs show the ratio of peers that had a specific number of stalls or stalling time. For T70/Q30 the highest number of stalls for any peer is 3. Furthermore, about 80% of the peers had less then 1 stall with T70/Q30, whereas for the media agnostic and DiffServ routers, those peers had around 2 stalling events.

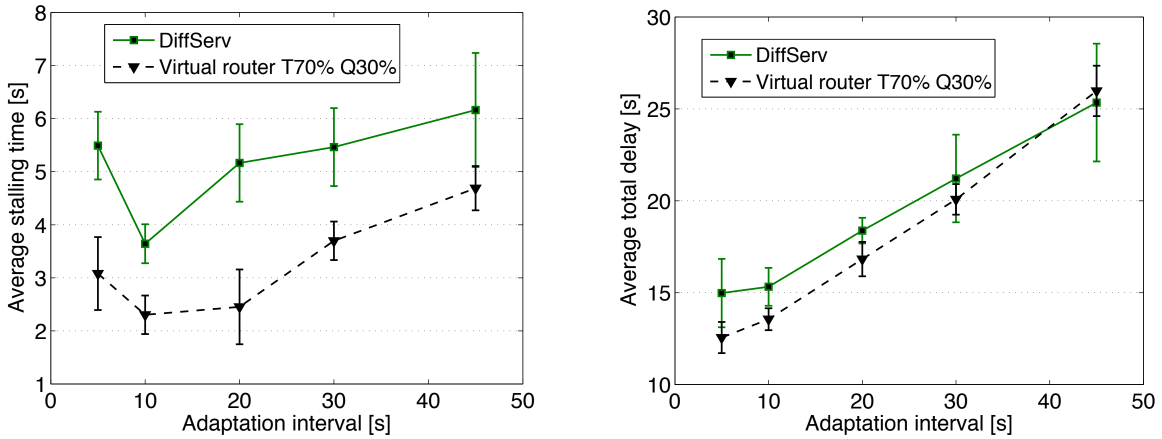
Video Quality. Now we take a look at the video quality during the bottleneck. The results are presented in Figure 4. We see that the number of layer changes during the bottleneck is affected by media awareness (Figure 4(a)), while the average relative quality is minimally affected (Figure 4(b)). Peers had the most layer changes with the media agnostic and DiffServ routers. This is due to the fact that those approaches have inflicted a larger number of stalls, which in turn caused the peers to adapt and reduce the requested layer, therefore, performing more layer changes. We can conclude that having media awareness leads to less quality changes because the peers are able to receive the requested quality. Again, the media-aware router with T70/Q30 yielded the best performance.

Concluding this experiment, we can say that media awareness based on a more weighted temporal priority (T70/Q30) has shown that video stalls and quality switches occur less often. Based on user studies [14, 13], our approach, therefore, helps in enhancing the perceived video quality since the video playback is smoother and has less quality switches.

4.4 Experiment 2: Variable PQA Interval

The second experiment deals with assessing the interdependencies between the PQA or adaptation interval and media awareness during a bottleneck. We want to check whether the adaptation interval depends on or affects our media-aware solution. Thus, we vary the adaptation interval choosing the values: 5, 10, 20, 30, and 45 seconds. We restrict our evaluation to the DiffServ and media-aware routers with T70/Q30.

Session Quality. Session quality with different adaptation intervals during the bottleneck and for the whole simulation are presented in Figure 5. We can see that our media-



(a) Average stalling time per peer during bottleneck

(b) Average total delay per peer during simulation

Figure 5: Session quality in Experiment 2

aware approach outperforms DiffServ. During the bottleneck, the average stalling time could be drastically reduced for the different adaptation intervals. Additionally, we see that for the DiffServ approach during bottleneck (Figure 5(a)), the relation between average stalling time and adaptation interval is not predictable, which is the case once the media awareness solution is in place. Therefore, media awareness is quite crucial especially in applications where the system provider would change the adaptation interval during runtime, which requires a more predictable relation.

Although the results for the total delay during the whole simulation (Figure 5(b)) do not show a huge performance gain over the whole simulation, it is the performance during the bottleneck that has the highest impact on the effective performance of the system, and therefore is more relevant.

Video Quality. Video quality in Experiment 2 did not show dependance on the PQA, so the graphs are excluded.

5. CONCLUSION

In this paper, we have presented a simple yet efficient media-aware network approach that achieves better perceived QoS without any additional traffic costs. This architecture, which is based on virtualized routers, enables building next generation multimedia applications.

We demonstrated that, during bottlenecks, our media-aware network improves both the session quality (regarding the total stalling delay) and video quality (regarding the need to switch the layer). Additionally, we saw that prioritizing video transmissions with more weight on the temporal aspect of video blocks brought the best performance and outperformed a DiffServ-based solution. More specifically, having a media-aware network helped in achieving 52% less stalling delay and 34% less SVC quality switches during bottlenecks. Regarding the interdependencies between the adaptation interval and media awareness, we saw that having more intelligence in the network makes the impact of the adaptation interval more predictable. This is especially important if this interval would be assigned dynamically depending on the device and network characteristics.

As future work, we plan to integrate the algorithms presented in this paper into a real virtual router and to perform prototype evaluation. To address more practical issues, we will study suitable control and management algorithms.

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