Quality of Service and Quality of Experience in Video Streaming

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Abstract— Real-time video sessions, such as IPTV and video streaming, will be among the most important applications in future networking systems. The delivery of those sessions based on *Quality of Service* (QoS) techniques assures packet differentiation and indicate the impact of multimedia traffic on the network performance, but do not reflect the user perception. Therefore, a combined control of QoS with *Quality of Experience* (QoE) support can assure the distribution of video content according to video content characteristics and the user experience, while optimizing the usage of network resources. This paper introduces the *QoS/QoE Adaptive Video Control* (2QAV) solution to control the quality level of video sessions in wired and wireless networks taking into account multimedia content, QoE and QoS aspects. Simulation experiments present benefits of the proposed solution on the user expectation by verifying QoS and QoE metrics.

Index Terms—*QoS, QoE, Adaptation, Video*

I. Introduction

Video streaming sessions are now contributing to enhance our life experience and will be even more present in our professional and personal activities in future generation networks. The distribution of those sessions for fixed and mobile users with *Quality of Service* (QoS) and *Quality of Experience* (QoE) support is a key issue to attract and keep customers, while increasing the profits of providers and optimizes network resources. From the network point of view, this challenge is mainly due to the lack of efficient packet distribution control techniques and the dynamic behaviour of shared wired and wireless resources. From the user point of view, video streaming sessions with QoE support must be accessible anytime and anywhere.

Traditional QoS-based schemes, such as *Differentiated Service* (DiffServ) [1] and *Integrated Service* (IntServ) [2], aim to assure the quality level of video sessions in a networking environment based on a set of network measurement and control operations. Currently approaches provide QoS assurances for video streaming sessions according to network/packet-based metrics. Examples of these metrics are throughput, packet loss, delay and jitter, which do not indicate the real impact on the video quality level from the user point of view. Consequently, existing QoS parameters fail in capturing subjective aspects associated with the *Human Visual System* (HVS) as well as in video frame adaptation control.

In order to optimize the usage of network resources and increases the video quality level, QoS control schemes must be performed taking into account the current network conditions, video characteristics and QoE support. With this goal in mind, an approach that combines QoS adaptation control, multimedia CODEC and human perception experience is required.

This paper introduces the *QoS/QoE Adaptive Video Control* (2QAV) solution that optimizes the usage of network resources, while keeping video sessions with acceptable quality level in congestion periods. The 2QAV approach is based on the coordination of QoS and QoE adaptation operations. By controlling the dropping of packets according to the importance of each video frame, 2QAV adapts video sessions to the current network conditions and reduces the impact of packet losses on the user perspective. This paper studies 2QAV in a DiffServ *Moving Picture Experts Group* (MPEG) environment, where DiffServ provides scalable traffic differentiation and QoS assurances for MPEG sessions. Additionally, simulation results present the benefits of 2QAV in keeping video sessions with acceptable quality levels in congestion periods, by analyzing *Peak Signal-to-Noise Ratio* (PSNR), *Video Quality Metric* (VQM), *Structural Similarity Index* (SSIM) and *Mean Option Score* (MOS) QoE metrics. Moreover, the percentage of packet losses for different adaptive control approaches during congestion periods is also measured.

The remainder of this paper is organized as follows. Section II presents an overview of subjects covered in the paper. Section III analyses related work. The 2QAV proposal is described in VI. Section IV introduces the 2QAV evaluation by using *Network Simulator 2* (NS2). Conclusions and future work are summarized in Section V.

II. Background

The section highlights a brief description about DiffServ QoS model, Video *Coder-Decoder* (CODEC)s and QoE metrics.

A. DiffServ QoS Model

Several QoS models have been proposed with the goal of enriching the Internet with QoS guarantees that the current Best-Effort model cannot support. Each model defines its own mechanisms and parameters for traffic control and policies. IntServ and DiffServ are the two major wired-based QoS models standardized by the *Internet Engineering Task Force* (IETF) for QoS support on the Internet. Regarding wireless QoS models, *Universal Mobile Telecommunication System* (UMTS), IEEE 802.11e and IEEE 802.16 models can be pointed out.

A DiffServ network is composed of a set of routers (edges and cores). The service provisioning is accomplished in accordance with traffic condition policies, where the incoming traffic is identified and classified by edge routers. Then

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packets are handled in each router by the traffic conditioner according to the *Per-Hop Behavior* (PHB) indicated by the *Differentiated Service Code Point* (DSCP).

Regarding the traffic conditioner, the meters are used to measure the traffic against a profile. Markers set the DSCP field of a packet to a class. Finally, the Droppers/Shapers control the drop of packets in order to bring the packets into compliance with a traffic profile. However Dropper/Shaper mechanisms do not differentiate packets of video sessions according to the importance of each frame (or other video characteristics) during the dropper process.

B. Video CODECs

The distribution of compressed video content aims to reduce significantly the amount of resources required for its transmission. Several video compression schemes have been proposed, such MPEG-2, MPEG-4 and H.264 [3]. All these video CODECs are based on the utilization of *I*, *P* and *B* frames, which uses a combination of *Discrete Cosine Transform* (DCT) and motion prediction on their encoding. Therefore, the original video is compressed (encoding) before the transmission and decompressed (decoding) after the reception.

As happens with H.264, MPEG encodes *I* frames by using spatial compression. To achieve temporal compression *P* frames are reconstructed using last *I* or *P* frame, while *B* frames are reconstructed using the last *B* or *P* frame and the next *B* or *P* frame. Therefore, *I* frames are more important than *P* frames and *B* frames are the less important ones. During streaming, packets pertaining to a video sequence are transported using *Real-Time Transport Protocol* (RTP). RTP packets describe information also about frame types (*I*, *P*, *B* frames) that can be used for video adaptation schemes.

C. QoE Metrics

Several subjective and objective methods exist to measure the quality level and detect impairments of video sessions. Subjective methods acquire information about the quality level of processed video based on human opinion score schemes, while objective methods are used to estimate the performance of video systems by using mathematic models that approximate results of subjective quality assessment.

The PSNR is a traditional objective metric used to measure the video quality level based on original and processed video sequences. Considering frames with *MxN* pixels and 8 bits/sample the PSNR is defined through the Equation 1.

$$PSNR = 20\log_{10}\left(\frac{255}{\sqrt{\frac{1}{M\,x\,N}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}\left\|Ys(i,j)-Yd(i,j)\right\|^{2}}}\right) \quad (1)$$

The PSNR only provides an indication of the difference between the received frame and a reference signal. To overcome this limitation, SSIM and VQM metrics were proposed to take HVS aspects into consideration during the evaluation process. The SSIM metric is based on frame-to-frame measuring of three components (luminance similarity, contrast similarity and structural similarity) and combining them into a single value, called index. The SSIM index is a decimal value between 0 and 1, where 0 means zero correlation with the original image, and 1 means the exact same image. Additionally, based on the original and processed video, the VQM metric outputs a value from 0 to 5 (0 is the best possible score) to present the video quality level based on human eye perception and subjectivity aspects, including blurring, global noise, block distortion and color distortion

Subjective metrics assess how video streams are perceived by users [4]. The most traditional subjective metric is named MOS. The quality level of a video sequence based on MOS model is rated on a scale of 1 to 5, where 5 is the best possible score. The PSNR metric can be used to map MOS values as described in Table 1.

TABLE I
MAPPING PSNR TO MOS

PSNR (dB)	MOS
>37	5 (Excellent)
31-37	4 (Good)
25-31	3 (Fair)
20-25	2 (Poor)
<20	1 (Bad)

III. RELATED WORK

There are several proposals to adapt the video content to the current network conditions.

A scalable video approach uses different resolutions to send video content depending on the available bandwidth, by performing the video re-coding, or maps packets to different DiffServ classes according to the importance of each layer and frames of a layer [5]. However, the mapping of layers in different classes with different delay and loss probabilities increases the system complexity to synchronize the packet reception, as well as, the use of transcoding requires high CPU consumption. In addition, poor evaluation experiments were performed to verify the behavior of the proposed solution, where only PSNR values of a video sequence were measured.

A QoE adaptive video control scheme adapts one-to-one basis video sessions, by controlling packet retransmissions and adjusting the amount of *Forward Error Correction* (FEC) packets [6]. However, the proposed solution increases the system overhead and needs a complex synchronization control scheme on the sender and receiver sides to re-transmit missing packets.

Considering approaches that assume different frame type importance in a video session, the improvement of *Single Rate Three Colors Marker* (SRTCM) or *Two Rate Three Colors Marker* (TRTCM) techniques have also been adopted. In [7], the quality level of video streaming is maintained by using the *Enhanced Token Bucket Three Colors Marking* (ETBTCM) approach to mark *I*, *P* and *B* frames with green, yellow and red colors, respectively. However, this approach requires changes in IP packet headers and extra modules in sources to perform source level mapping control, which reduce the system flexibility.

In [8] *Bit-based Weight time Slot Compensate* (BWSC) scheduling algorithm to *Variable Bit Rate* (VBR) traffic of video is introduced. The BWSC algorithm adjusts the quality of real-time VBR burst traffic dynamically, by reducing the video end-to-end delay. To achieve this goal, the proposed solution divides MPEG4 content into two DiffServ classes, called DiffServ AF1 (based on *First In First Out* (FIFO)) and DiffServ AF2 (based on *Red In/Out* (RIO)). Then, packets are sent in each class according to session QoS requirements in terms of bandwidth and delay requirements. In addition, the evaluation of the proposed algorithm is based only on non-subjective metrics, named as PSNR and delay.

The analysis of related work has shown that most adaptation proposals requires changes in end-hosts or increases the system overhead. In addition, existing approaches do not consider dependency of each frame of a sequence during the adaptation process neither provide flexible video adaptation schemes. Moreover, the performance evaluation of the current solutions was poor and does not verify the real impact of their solutions from the user point of view. To overcome the identified limitations, the next section presents the 2QAV solution.

IV. QoS/QoE Adaptive Video Control

The 2QAV proposal controls the quality level of video sessions and optimizes the usage of network resources, by providing an intelligent control mechanism to discard packets in congestion periods. The proposed adaptation mechanism can be configured with different selective dropping levels, where a percentage of discarding associated with video and non-video traffics can be assigned to be used during adaptation process. For example, in congestion situations, video traffic can be protected to be discarded latter (concurrent traffic is dropped first) or the system can be configured to drop only 10% of all video packets.

In order to increase the system flexibility, 2QAV was developed as modular as possible. The modularization allows network operators to configure QoS models, video CODECs, and selective dropping levels of their choice. Furthermore, other relevant control information can be included in the adaptation decision process, such as layered video coding aspects (if used), video cost/price, high-rate videos and session population size. For instance, the dropping percentage of video sessions with small audience can be increased in order to protect sessions with large number of receivers. The procedure to decide which 2QAV adaptation control strategies must be used inside or between networks can be done either static (manual/pre-defined) or dynamic (by using signalling messages) operations. The 2QAV functionalities are implemented at edge routers together or other wired or wireless network elements with traffic control functionalities.

2QAV has two operational modes as follows: (*i*) in its basic configuration, 2QAV adapts video sessions to the current network conditions, by dropping frames only according to their importance in order to keep the system as simple as possible (low processing and state stored). (*ii*) In its enhanced configuration, 2QAV can adapt the video quality level also taking into account the dependency of video sessions [9] and other relevant control information, such as audience size or cost as well as 2QAV can increase the number of non-video packets to be dropped. Since, video sessions are data streams containing application-level objects with special proprieties and dependence, 2QAV improves the packets dropping based on the dependency of a set of frames. For example, the last *B* frames of a MPEG-2 *Group of Picture* (GOP) depend on the first *I* frame of the following GOP. Therefore, if such *I* frame cannot be admitted in a network (edge router), the last *B* frames must also be dropped in order to optimize the usage of network resources. A typical MPEG-1/2/4 structure is presented in Figure 1 and a detailed description is available in [9].

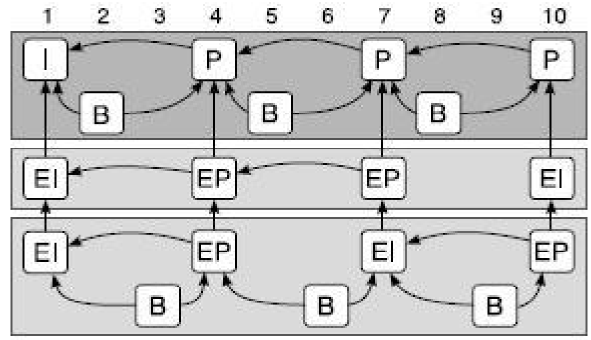

Fig. 1. A typical MPEG-1/2/4 structure

In order to describe the impact of 2QAV in a networking system, the remainder of this paper shows a brief description about the usage of 2QAV in a DiffServ MPEG system. DiffServ and MPEG were chosen to exemplified, because they are well-known standards implemented in several networks and applications.

As described in Section II.A, the DiffServ model performs metering, shaping, dropping and other traffic control operations to manage the incoming traffic according to the rules specified in the traffic conditioner element. Traditionally, the traffic conditioners only take into account the total rate of the traffic aggregated in the service and his capacity. Therefore, all incoming flows are handled in the same way (without taking into consideration the packet content or importance).

In order to improve the usage of network resources and the quality level of videos, 2QAV is configured to extend the DiffServ meter, shaper and dropper elements. When there are available resources in a network to accommodate all incoming packets, all packets are marked as green. When tokens are insufficient for all packets to pass, 2QAV verifies its adaptation policies (basic or enhanced configuration) and interacts with the maker element to, for instance, mark less important video frames (*B* frames) as red and more important video frames (*P* and *I* frames) as yellow. Alternatively, the marker can also define in-profiles and out-profiles packets also according to the population size (or other enhanced control information), where *I* frames associated high audience sessions are marked with lowest drop precedence.

If DiffServ is configured with *Random Early Detection* (RED) to control the queuing of in-profiles and out-profiles, 2QAV enhances RED with its intelligent discard control scheme. For example, when the system is configured with 2QAV basic configuration and the queue is full, an out-profile packet (low priority frame) is randomly discarded. Only in the absence of out-profile packets, an in-profile packet (high priority frame) is dropped. By controlling the video quality level in congestion periods, 2QAV aims to increase the satisfaction of users and optimizes the usage of network resources.

V. Performance Evaluation

Performance evaluation of the 2QAV proposal in a QoS multimedia environment was carried out by using the *Network Simulator 2* (NS2) [10]. The Evalvid platform [11, 12] was also implemented to evaluate the video quality delivery and configured to support MPEG *I*, *P* and *B* frames. 2QAV was evaluated in a QoS-aware DiffServ and MPEG environment, where RED is used to control the queuing.

The main objectives of the simulation experiments are the following: (*i*) analyze de percentage of packet losses associated with frames of video and non-video sessions and (*ii*) analyze of the perceived quality of a video sequence by verifying PSNR, SSIM, VQM and MOS. The following four main approaches were used to highlight the 2QAV benefits: *Best-Effort* (no traffic differentiation), *DiffServ* (with traffic differentiation without 2QAV support), *2QAV* (DiffServ with 2QAV basic configuration – most important frames are protected) and *2QAV with 3% Advanced Drop* (DiffServ with 2QAV enhanced configuration – most important frames are protected and 2QAV increases the percentage of non-video packets to be discarded in 3% in order to protect more video packets). For each approach, 10 experiments were performed with different congestion rates (from 0 up to 300% of congestion in a system).

2QAV module was implemented in NS2 and DiffServ marker and dropper/shaper traffic conditioner components were modified. Therefore, packets are firstly marked according to there content (video and non-video) and dropped based on the importance of each frame. Regarding to frame priority, if an *I* frame is market to be discarded, the dropper tries to find a *B* or *P* frame in queue to be dropped in order to protect most important frame. In addition to the frame differentiation, the *2QAV with Advanced Drop* scheme increases the percentage of non-video traffic to be dropped in congestion periods (3% in this simulation). For example, if a *B* frame is marked to be dropped and a *Constant Bit Rate* (CBR) packet exists on queue, then the CBR packet is dropped and the video frame is marked to be protected/in-profile. In order to avoid inter-class packet differentiation (e.g., unfair packet dropping), both CBR and video packets are mapped to the same physical queue, but accommodated into virtual queues with different drop precedence.

In addition, *The Boston Representative Internet Topologies Generator* (BRITE) [13] was used to generate a random topology for the evaluation. Figure 2 illustrates the evaluated scenario, which is composed of 2 sources, 2 receivers, 4 edge routers and 21 core routers. The links have a bandwidth of 2Mb/s and their propagation delay was assigned according to the distance between the edges of each link. Each source sends a real video sequence with average rate of 350Kb/s and a CBR traffic in order to congest the links (overloading 2Mb/s links with 8Mb/s). The video sequence, denominated "Akiyo" [14], consists of 300 frames (30 frame/s) with YUV format, sampling 4:2:0, dimension 352x288. The video sequence was compressed through a MPEG-4 CODEC. The GOP of the sequence is composed of 30 frames and being used two *B* frames for each *P* frame. Frames are then fragmented in blocs with 1024 B.

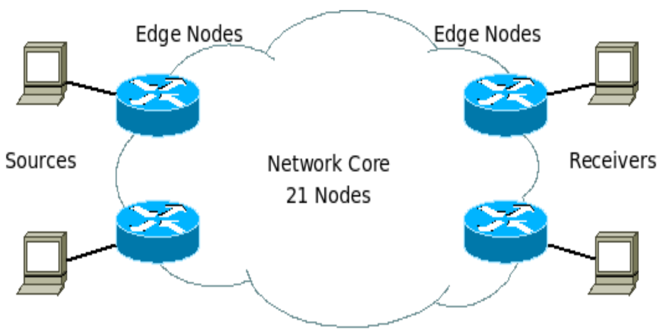

Fig. 2. Topology

A. *Frame Losses*

This Section measures the percentage of frame losses (*I*, *P*, *B* and other frames/CBR) for different congestion rates when a system is configured with Best-Effort, DiffServ, 2QAV and 2QAV with 3% Advanced Drop approaches.

As presented in Figure 3, when the system is implemented only with the Best-Effort approach, packets are discarded in a random manner. Hence, the percentage of packet losses are increased proportionally for all frame types (including packets associated with the CBR traffic) when the network congestion increases.

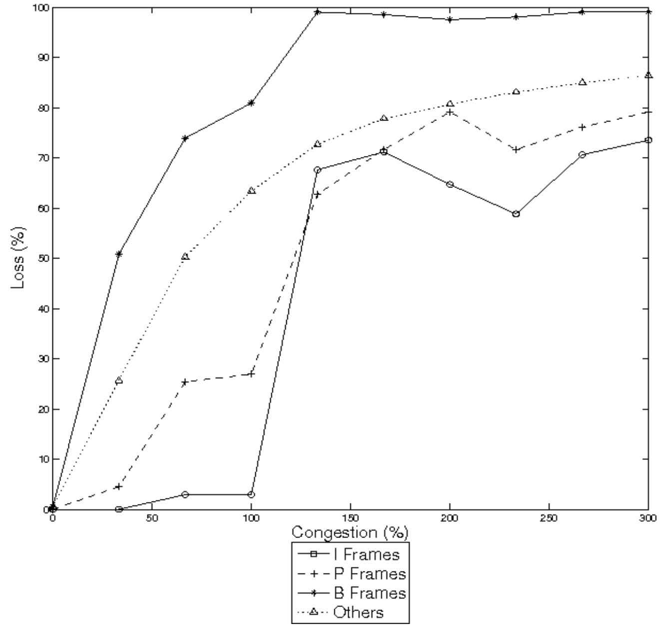

Fig. 3. Percentage of losses for each frame type and congestion rates when the Best-Effort approach is used

Figure 4 describes the system behavior when the DiffServ approach is being used. The results reveal that DiffServ provides packet differentiation and protect video packets (compared to Best-Effort class), because they are accommodated in a most important class. However, inside the AF class, all video packets are dropped in a "black-box" random way (without frame type differentiation).

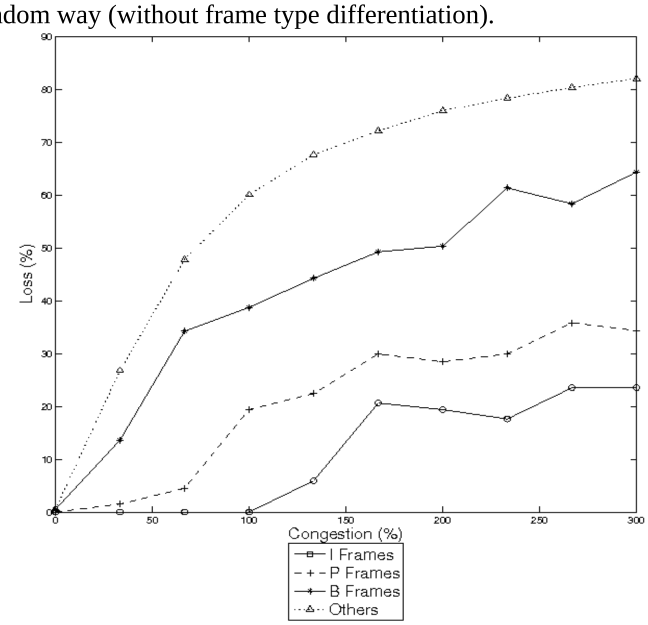

Fig. 4. Percentage of losses for each frame type and congestion rates when the DiffServ approach is used

The benefits of 2QAV proposal on the video quality level are depicted in Figure 7. By adapting the video content according to the importance of each frame, the 2QAV aims to protect most important video frames in congestion periods. Hence, *B* frames are dropped first and *I* frames are the last ones to be discarded, which increases the user's experience. Compared to Best-Effort and DiffServ approaches, 2QAV reduces the percentage of *P* frame loss in 60% and 23%, respectively, when the system overload is 100%.

Due to its frame protection schemes, *I* frames are not discarded during simulations when the 2QAV and 2QAV with 3% Advanced Drop approach are configured. However, compared to the 2QAV solution, the percentage of *P* and *B* frame loss is decreased in 66% and 30% respectively, while the percentage of CBR packet loss is increased only in 3%. Notice that there are more CBR packets than video packets in the system and consequently more non-video packets are discarded during congestion periods.

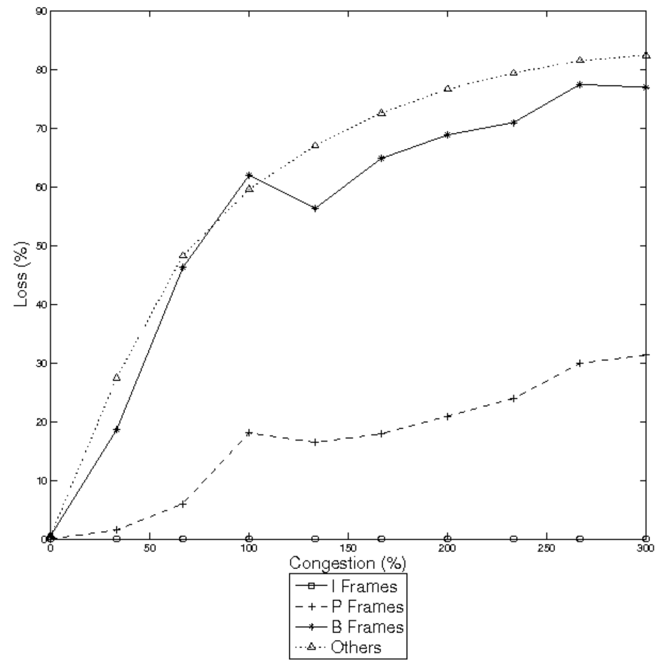

Fig. 5. Percentage of losses for each frame type and congestion rates when the 2QAV approach is used

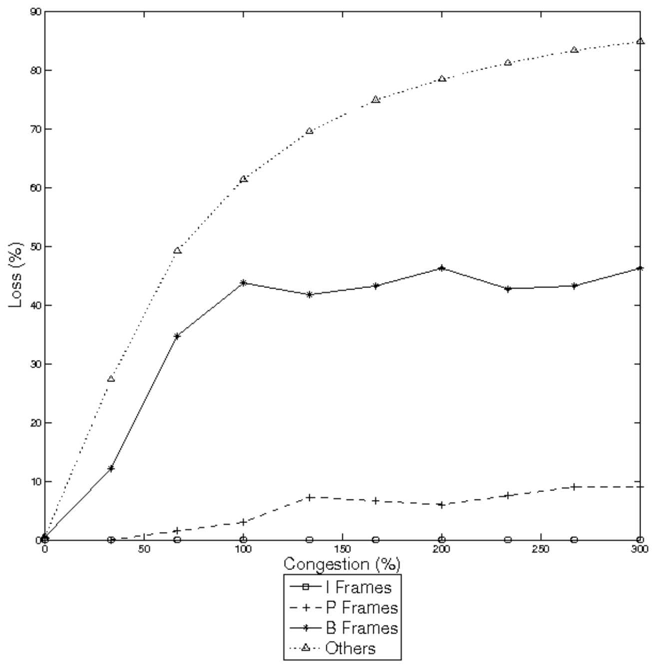

Fig. 6. Percentage of losses for each frame type and congestion rates when the 2QAV with 3% Advanced Drop approach is used

B. Peak Signal to Noise

Since packet loss rate does not indicate the real impact on the video quality level, PSNR values of the video sequences in different congestion periods were analyzed. Figure 6 shows the average PSNR for the videos with different approaches.

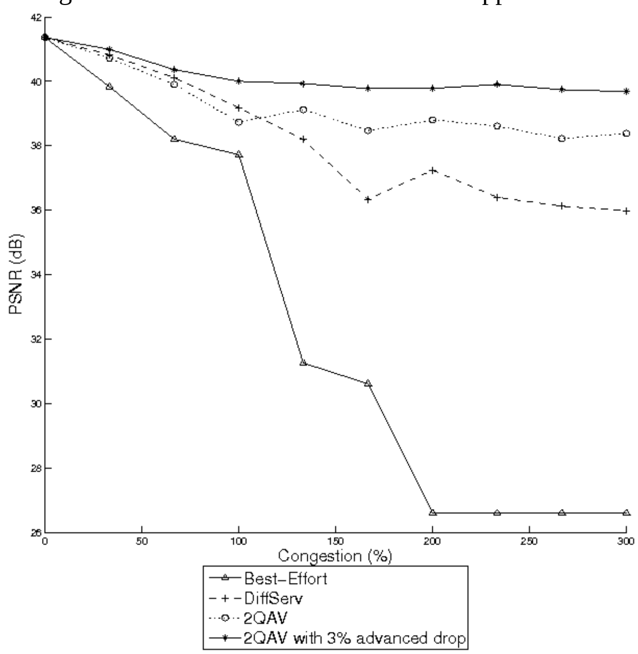

Fig. 7. PSNR for each approach and congestion rates

The results reveal that when the Best-Effort approach is being used, the PSNR of the videos decreases as fast as the traffic increases, getting a minimum value of 27dB. When the system is configured only with DiffServ, the PSNR of the videos is maximized in comparison with the Best-Effort (e.g., the PSNR is increased in 3% when the network is overloaded in 80%). Compared to the DiffServ approach, 2QAV increases the quality level of video sequences in 3% and 6% when the system is overloaded in 130% and 150%, respectively. Compared to 2QAV, 2QAV with 3% Advanced Drop increases the video PSNR on average 2% for all experiments.

C. Structural Similarity Index

SSIM results give more detail about the video quality level taking human perception into account. Figure 8 illustrates the average SSIM of the video sequences when the system is configured with Best-Effort, DiffServ, 2QAV and 2QAV with 3% advanced drop approaches.

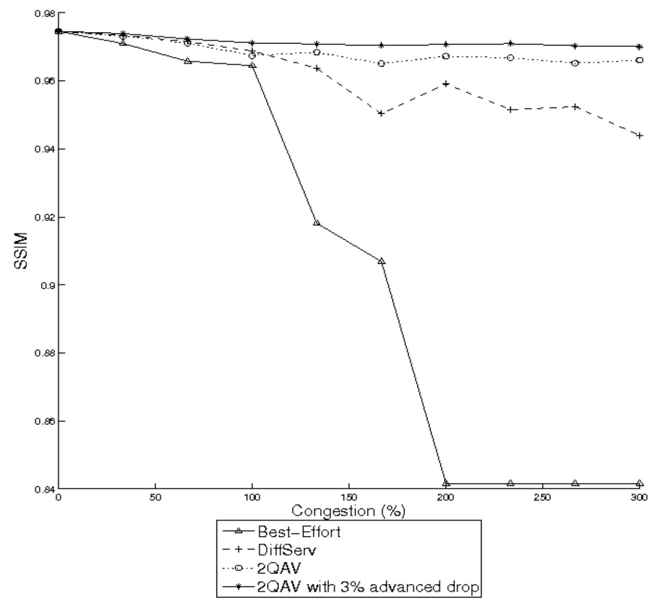

Fig. 8. SSIM for each approach and congestion rates

The results reveal that when the Best-Effort approach is configured, the correlation between the original and received video is poor after a congestion of 100%. Compared to DiffServ, 2QAV increases the SSIM of video sequences in 3% when the system is overloaded in 200%. On average, the 2QAV with 3% Advanced Drop approach increases in 0.5% the video SSIM for all experiments compared with simulations based only on the 2QAV approach.

D. Video Quality Metric

VQM is an important metric to verify the video quality level based on human eye perception and subjectivity. Figure 9 presents the average VQM results for each approach when the system has different congestion levels.

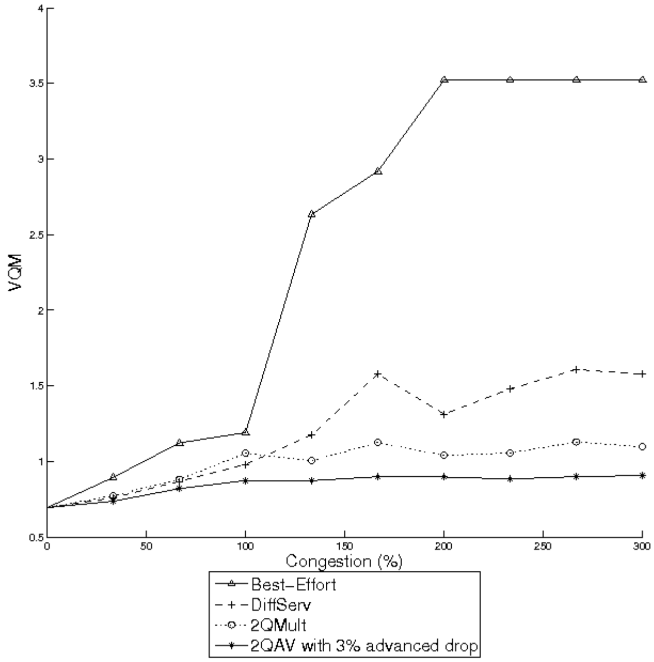

Fig. 9. VQM for each approach and congestion rates

Due to its packet differentiation scheme, the DiffServ approach increase the video VQM in 18% compared to Best-Effort when the system load is 80%. Additionally, during a congestion period of 100%, 2QAV increases the video VQM in 43% and 70% when the system is configured with DiffServ and Best-Effort approaches, respectively. Compared to a system with 2QAV, the 2QAV with 3% Advanced Drop approach maximized the video VQM on average 15% when the system is overloaded in 120%.

E. *Mean Opinion Score*

In order to present the user experience for each approach during congestion periods, the video quality level was evaluated, by using MOS and illustrated in Figure 10.

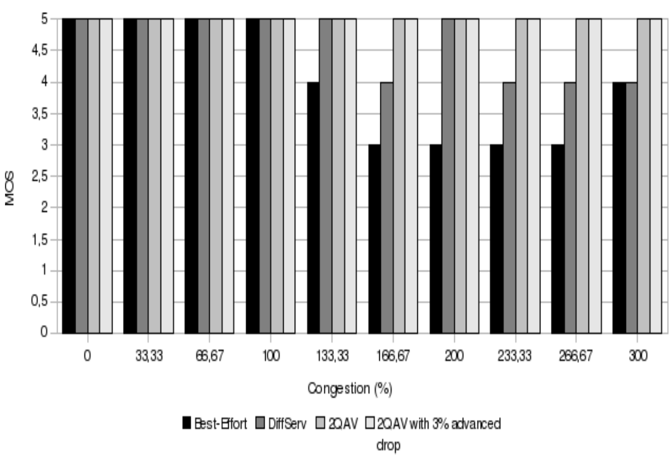

Fig. 10. MOS variation when network load increase.

The results reveal that according to the MOS metric, 2QAV and 2QAV with 3% Advanced Drop approaches kept videos with an excellent quality level during all congestion periods. The video degradation and its poor quality are visible when the system is overload (100% of congestion) and DiffServ is configured as illustrated in some frames of Table II. With DiffServ, the journalist's face area is damaged due to the loss of important frames.

TABLE II
SOME FRAMES WITH DIFFSERV AND 2QAV

DiffServ	2QAV
	
	

From Table II, it is evident that, by protecting most important video frames, 2QAV increases the user satisfaction, while optimizing the usage of network resources (the same amount of resources are used in both approaches, but the video quality level is different).

VI. CONCLUSION

This paper introduces the 2QAV proposal, which controls the quality level of video sessions and optimizes the usage of network resources in congestion periods. The 2QAV adaptation control is performed by providing an intelligent discard of video and non-video packets. The 2QAV discard controller enhances the video quality level perceived by users. Even though 2QAV was exemplified with MPEG and DiffServ, its interfaces allow operators to use any other CODECs and QoS models as well as additional video control information, such as video region of interest or motion.

The simulation reveals that both 2QAV approaches aim to keep videos with an excellent quality level during congestion periods. Compared to 2QAV in a network with 50% of congestion, 2QAV with 3% Advanced Drop increases the video PSNR, SSIM and VQM in 1%, 0.3%, 7% respectively.

As future work, 2QAV will be extended to adapt also audio and video sessions, by protecting audio components in congestion periods. The 2QAV benefits in wireless networks and with different CODECs will be investigated.

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