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When does lower bitrate give higher quality in modern video services?

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***Abstract*—Due to the difficulties on approximating the human perception with algorithms, increasing the users Quality of Experience (QoE) in modern video services is a challenging task. But more than that, prior to estimating QoE, it is important to know how different types of network impairments actually affect the video quality. This paper takes a closer look at the relation between the network quality of service (QoS) and the video QoE degradation. Using a sophisticated network emulation environment, we benchmark a range of video types and video quality levels under controlled network conditions. Our analysis shows that, along with a number of expected situations come also some counterintuitive QoS-to-QoE conditions. We discuss ways in which a better understanding of the mutual influence between networks and video streams could lead to more efficient utilization of the Internet.**

Keywords*—*Quality of Experience, video services, video quality assessment, network impairments.

I. INTRODUCTION

In the era of Web 2.0 in which the network is considered as a platform for information sharing, collaborations and interoperability, the importance of media streaming is increasing and we have to be prepared for what will come next [1], [2], [3], [4]. Just thinking on everyday's life it is easy to see how much this is true: video lectures, live streaming of events, video blogs and more [5]. In spite of the development of communication systems, as Internet and third generation mobile radio networks, one issue remains: in any case, a level of degradation is still experienced by the end user due to impairments caused by the network [6]. Users have some expectations on their experience while using a service. Thus, service providers have to be aware of the quality of their services, in terms of Quality of Experience(QoE) [7], [8], [9], [10] and not just in terms of Quality of Service (QoS) [11], [12]. For this reason, studying how and to which extent different network conditions affect the quality of video streams is fundamental [13]. Expressing the users' satisfaction is still an open challenge in the field of research since it is something very subjective. Moreover, it depends not only on personal judgment, but also on the user's expectations, which can vary with the device (a personal computer, a tablet, a smartphone), the network used (wired, wireless, mobile network) and also the type of video watched [14]. In other words, it focuses on how different kinds of videos are affected by different network conditions. The appropriate methods to reflect the human perception are the subjectives QoE methods [15], [16], because they involve humans to evaluate human perception factors [17]. It is not always possible to employ subjective tests, particularly when the application requires real-time feedback for service monitoring and control. For this reason in this paper objective metrics [15] are used to assess the video quality which in contrast with subjective metrics, offer more advantages from an economical and practical perspective. All the experiments were run in a controllable and repeatable laboratory setting using Hurricane II PacketStorm network emulator. We show that not all results are according to expectations, pinpointing some interesting findings.

The remainder of this paper is organized as follows. Section II, presents background knowledge on objective QoE assessment for the benefit of the non-specialist reader. Section III, details the experimental setup. Section IV, describes the experiments performed and reflects upon the attained results. Finally, Section V concludes and presents directions of future work.

II. BACKGROUND

In this section, one widely used objective QoE algorithm [18] for Video Quality Assessment [19], used in Section IV to assess the quality of the impaired videos, is briefly presented. It can be applied to videos by doing a frame by frame comparison on the original and the distorted videos, and afterwards by averaging the results. This algorithm is Structural Similarity (SSIM) [20], [21] which was created as a method for quality assessment of images, and it is considered to be correlated with the quality perception of the Human Visual System (HVS). SSIM is based on the observation that a natural image is highly structured. This means that there is a strong neighbor dependence between the pixels. Since HVS is highly adapted to structural information, this should be taken into account while measuring images similarity. Structural information is defined as the attributes that represent the structure of objects in the scene, independent of the average luminance and contrast [21]. Hence the influence of the illumination should be separated to study the structural information.

III. EXPERIMENTAL SETUP

This section describes the experimental setup used to evaluate the effects of the network impairments on video streaming

Acronym	Name	Description
River	River Bed	Still camera, shows a river bed containing some pebbles in the water.
People	Pedestrian Area	Still camera, shows some people walking about in a street intersection.
Bee	Sunflower	Still camera, shows a bee moving over a sun-flower in close-up.
Traffic	Rush hour	Still camera, shows rush hour traffic on a street.
Train	Station	Still camera, shows railway track, a train and some people walking across the track.
Badge	Shields	Camera pans at first, then becomes still and zooms in; shows a person walking across, and a display pointing at it.
Stockolm	Stockolm	Panning view over the Old Town of Stockholm..

TABLE I. DESCRIPTION OF THE VIDEOS UNDER SCOUTING.

applications. The overall architecture is depicted in Fig. 1 and detailed further. The videos used in the experiments contain

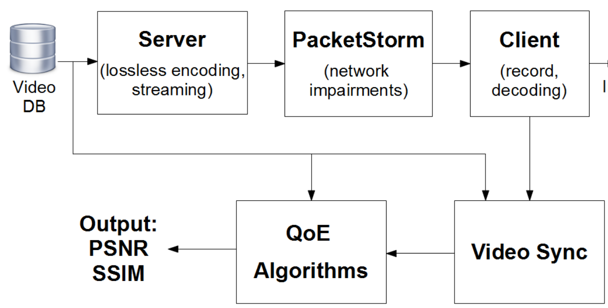

Fig. 1. Experimental setup diagram

low (LD) and high definition (HD) videos from the Live Video Databases [15] in RAW format and they are presented in Table I. Each video has 10 seconds length and a rate of 25 frame per second (FPS). Starting from this set of videos, each video is encoded using FFmpeg. Then, FFmpeg is also used to stream the MP4 video to the client with the Real-time Transport Protocol (RTP)[22] over UDP. RTP provides end-to-end network transport functions suitable for applications transmitting real-time data, such as audio and video over IP networks. The data transport is augmented by a control protocol (RTCP) to allow monitoring of the data delivery, and to provide minimal control and identification functionality. RTP and RTCP are designed to be independent from the underlying transport and network layers. The next step is to simulate the passage of the stream through a network causing several types of impairments. The network is emulated through a Hurricane II PacketStorm IP Network Emulator, which belongs to a family of general purpose IP network emulators designed to stress and test IP applications, hardware and software. On the client side, FFmpeg records the stream as a MP4 file. The video is then decoded and stored in the Impaired Video Database. At this point of the workflow, there are two sets of RAW videos: one set of original unimpaired videos and one of impaired videos. These two sets can be firstly synchronized, to identify the corresponding frames (between original and distorted sequences), and secondly compared using the algorithm presented in Section II.

IV. EXPERIMENTS AND RESULTS

In order to study the effects of network impairments on video streaming, a wide set of experiments is performed in a step wise fashion and detailed further.

A. *ITU G-1050/ TIA-921 and Internet in a box*

In the first type of experiments a real impaired network is simulated using the Hurricane II PacketStorm IP Network Emulator and the ITU G.1050/ TIA-921 International recommendation. The ITU G.1050/ TIA-921 is a network model for evaluating multimedia transmission performance over the internet protocol. It focuses on the impact of impairments on Layer 3. The IP network model consists of impairment combinations that are scenario based, time varying IP network impairments, which provide a significant sample of impairment conditions. It is composed by 48 test cases, clustered in 8 big groups A, B, C, D, E, F, G, H in an increasing order of impairments severity, ranging from $20ms$ to $1200ms$ of delay, 0% to 1% packet loss, $5ms$ to $500ms$ jitter, as it is depicted in Fig. 2.

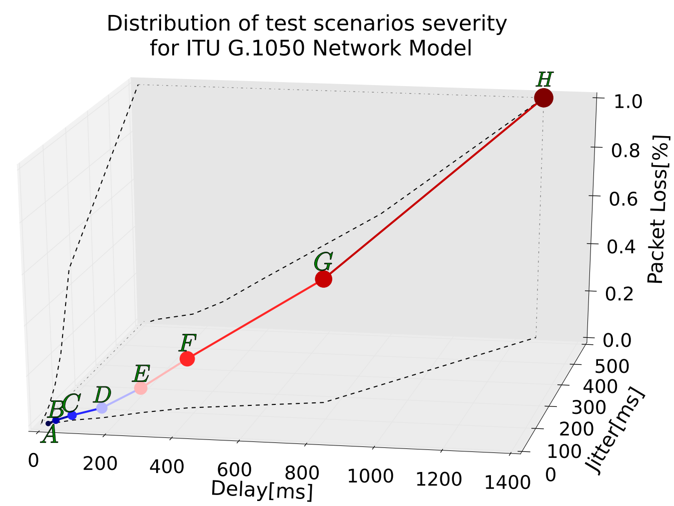

Fig. 2. All ITU G.1050 scenarios used in the experiments, grouped by severity. Blue points are characterized by a small amounts of impairments, while the darker red points have a big number of impairments.

By analyzing the results obtained from the simulations, we have discovered that the factor which influences the most the quality of a streamed video is the packet loss. In Fig. 3, the previous proposition is clearly reflected. More exactly, for the test cases A, B, C, D, E and F, where the values of packet loss in under 0.20%, the quality of the streamed ”river” video, which is the most difficult video to encode due to the reflection property of the water, is preserved very well and it is almost 0.9 using SSIM. However, as soon as the values of the packet loss are increased to 0.5% and 1% in test cases G and H, the quality of the streamed video drops dramatically, reaching 0.76 in the end.

Having in mind that packet loss affects the video quality in streaming applications, but still considering the effect of delay

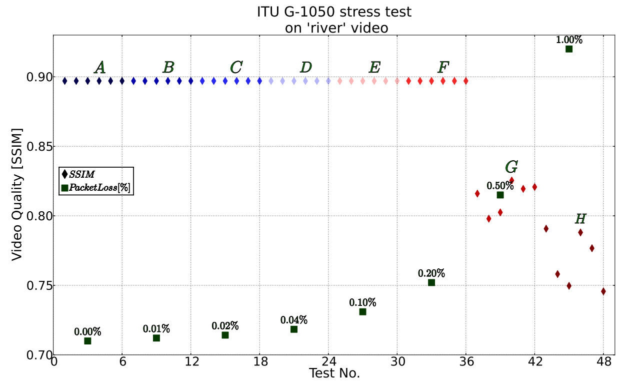

Fig. 3. Quality evaluation of "river" video streamed over 48 real network scenarios.

we proceed to the next phase of experiments.

B. Variable delay and packet loss; fixed quality

In the second type of experiments we study how low and high definition videos streamed at a fixed quality are affected by variable network conditions (i.e. variable delay and packet loss). More exactly, the videos from Table I are transmitted through the network at a fixed quality, while the packet loss and delay are linearly increased from 0% to 8% and $0ms$ to $100ms$, respectively. The quality of the impaired videos obtained is then measured against their original version using SSIM. Overall, the videos behave as we expected and the quality of the streamed videos decreases with the increasing amount of packet loss, while the delay does not have a powerful effect on it. However, as it can be seen in Fig. 4, we have glimpsed an unexpected result: for the same network conditions the high quality videos are more affected than the low quality videos. This observation leads us to the next round of experiments.

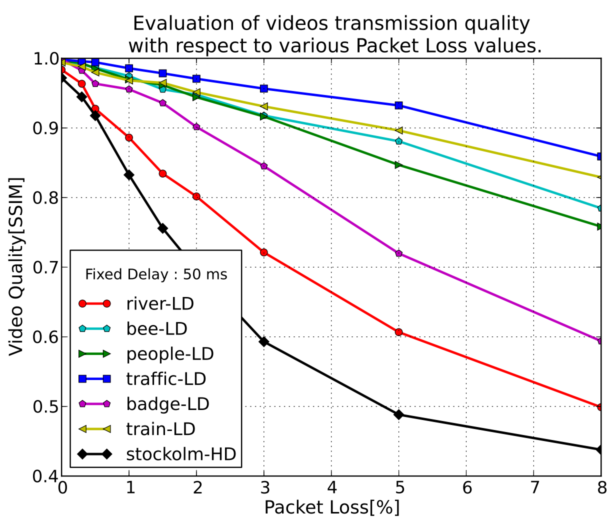

Fig. 4. The effect of packet loss on seven streamed videos, 6 in low definition format (LD) and 1 in high definition format (HD).

C. Fixed delay; variable packet loss and quality; LD

Based on the results obtained in the previous scenarios, in third phase of the experiments we study how the network conditions affect the video streaming, when the packet loss is increasing and the quality of the video is not fixed anymore. For this analysis, we pick the most representative

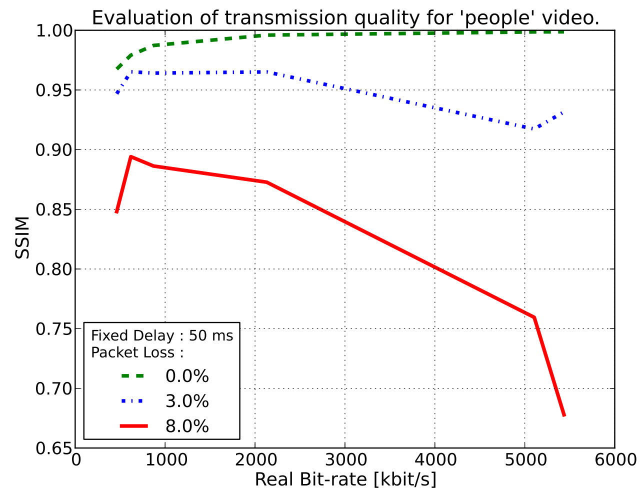

Fig. 5. The effect of a gradually increased bit-rate on the streaming of "people" video. Snapshots on three values of packet loss.

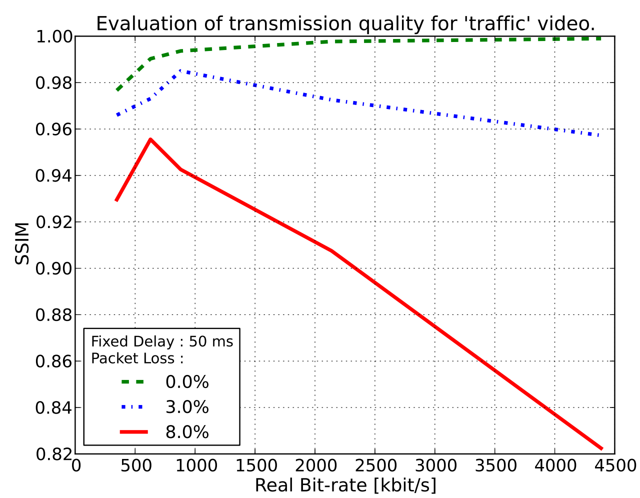

Fig. 6. The effect of a gradually increased bit-rate on the streaming of "traffic" video. Snapshots on three values of packet loss.

videos: "traffic"- best behavior, less affected by the network impairments; "people" - medium behavior; "river" - worst behavior, heavily affected by the network impairments. Each of them is defined in low resolution (i.e. 768x432). Due to their specific characteristics the real bit-rate for the videos is gradually increased as explained next: "traffic" from $347kbps$ to $4386kbps$, "people" from $462kbps$ to $5436kbps$, and "river" from $1340kbps$ to $10280kbps$. For all videos the packet loss takes the following values: 0%, 0.3%, 0.5%, 1.0%, 1.5%, 2.0%, 3.0%, 5.0%, 8.0%. This specific scenario leads us to

PacketLoss[%] Real Bit-rate[kbps]	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
2849	0.82	0.52	0.58	0.56	0.62	0.57	0.48	0.51	0.43	0.42	0.44
2968	0.81	0.79	0.66	0.53	0.63	0.50	0.43	0.41	0.40	0.44	0.43
3046	0.80	0.54	0.49	0.61	0.45	0.46	0.49	0.42	0.39	0.43	0.40
3197	0.80	0.71	0.47	0.50	0.47	0.49	0.44	0.46	0.37	0.37	0.37
4052	0.84	0.78	0.69	0.48	0.53	0.44	0.50	0.37	0.36	0.41	0.37
6829	0.89	0.56	0.46	0.48	0.40	0.50	0.42	0.41	0.43	0.35	0.36
9642	0.91	0.73	0.49	0.47	0.45	0.42	0.37	0.37	0.38	0.36	0.37
14607	0.93	0.54	0.44	0.38	0.46	0.40	0.39	0.38	0.33	0.34	0.34
19440	0.92	0.53	0.49	0.38	0.39	0.37	0.35	0.38	0.37	0.31	0.32
29431	0.93	0.79	0.60	0.36	0.41	0.38	0.39	0.35	0.33	0.35	0.32

TABLE II. SSIM VALUES ON "BADGE" VIDEO

discover a set of interesting and even counterintuitive results. As we expected, when the packet loss is low, SSIM values grow with the increasing video quality, more exactly with the bit-rate. On the contrary, when the packet loss is high, SSIM values trend decreases with a growing bit-rate. To make this evident, in Fig. 5, 6, and 7 we plot SSIM values of the three videos with a fixed packet loss percentage and with their real bit-rates. It is clear that increasing the bit-rate, helps improving the quality of video streaming services but just until an equilibrium point. After that point, if the bit-rate is further increased, in presence of unexpected network impairments (i.e. increasing of packet loss), it yields in a worse quality of the video streaming services. However, to make our conclusion more evident in Fig. 8 the SSIM values for all three videos are shown in parallel with an increasing bit-rate and a fixed packet loss of 8%. To confirm these results achieved so far we proceed to the last phase of the experiments.

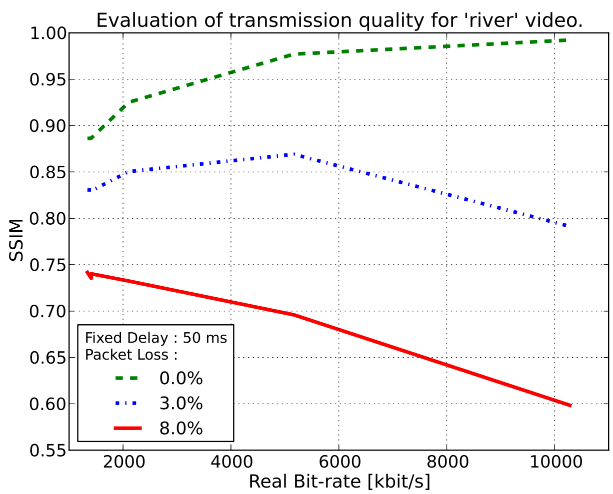

Fig. 7. The effect of a gradually increased bit-rate on the streaming of "river" video. Snapshots on three values of packet loss.

D. *Fixed delay; variable packet loss and quality; HD*

In the last phase of the experiments, we test a high resolution video characterized by a medium to high affected behavior on network impairments to confirm the results achieved so far. More precisely the "badge" video is used and its resolution set to 1920x1080. The real bit-rates are set to 2849, 2968, 3046, 3197, 4052, 6829, 9642, 14607, 19440 , and 29431 $kbps$. The packet loss is then gradually changed from 0% to 10% in unitary steps. As it can be seen in Table II, the lower quality videos initially, in presence of small packet losses, perform worse than the high quality videos. But, as the packet loss is gradually increased, the low quality videos manage to have better performance than the high quality ones.

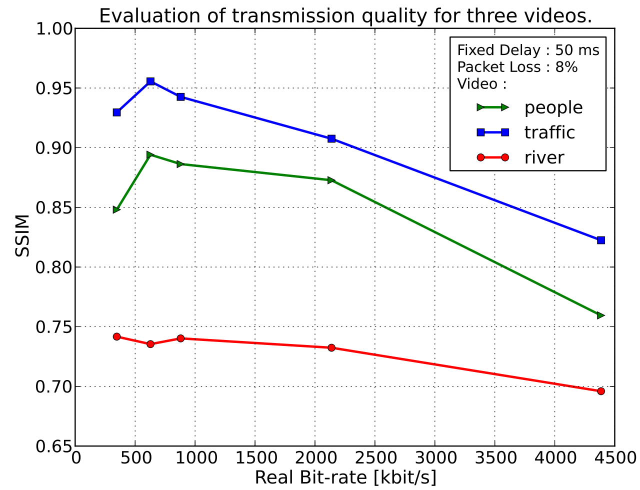

Fig. 8. Comparison of the effects yield by a gradually increased bit-rate on the streaming of three videos with fixed packet loss of 8%.

V. CONCLUSION

In this paper we studied how the network impairments affect the modern video network services to improve the user's Quality of Experience using a wide set of network conditions. In order to analyze these we used a sophisticated network emulation environment in which we benchmarked a range of video types and video quality levels. We discovered that packet loss influences the most on the quality of video streaming. This influence is independent from the video content type. More than that, some unexpected and counterintuitive results have been revealed. After evaluating the experiments, we can assert that, in the same conditions of network impairments, low quality videos streamed over the network perform better than high quality videos. As we gradually increase the severity of the impairments the previous statement becomes more evident.

As further work we intend to find the equilibrium point of the transmission quality. This point should offer us both, good quality of the video received over the network, and at the same time the most robust and less affected by unpredictable network impairments.

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