User Perceived Quality of Service in Multimedia Networks: a Software Implementation

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***Abstract*— Providing Quality of Service (QoS) has always been an important issue for Internet Service Providers. However, the proliferation of new multimedia content services in the last decade has turned it a vital and challenging feature. The problem with QoS in nowadays Internet is what to measure and how to do it in order to assure real quality levels to end-users. Recent work in the field has focused its attention towards the service consumer, assessing the QoS as perceived by the end-user.**

This paper addresses the problem of automatically evaluating the QoS Perceived by a user (PQoS) of a multimedia service. We first compare the performance of different techniques used for PQoS estimation in video and voice services over IP (VideoIP and VoIP). [1] We also develop an original software tool that integrates all the aspects related to the automation of the estimation process, using a broad set of methodologies on each case. To the date and to the best of our knowledge, there is no software implementation that completely estimates the PQoS for a VoIP and VideoIP service, solving all the intermediate steps between the selection of the service and the final result in a real environment. This tool allows not only to perform the estimation but to perform an unbiased comparison of the proposed techniques in the field.

I. Introduction

In the domain of traditional telecommunications, quality of service (QoS) has always been focused on network parameters, looking for different ways of keeping particular sets of them within certain limits, in order to assure the user reasonable quality levels. The problem with this approach is that in today's Internet, the heterogeneous features of current services make it difficult, sometimes even impossible to clearly identify the relevant set of performance parameters for each case. Even more, the quality experienced by a user of new multimedia services not only depends on network parameters but also on higher layers' characteristics [1] (coding and compression of the multimedia, recovery algorithms, nature of the content, etc...). In this sense, a final user might experience acceptable quality levels even in the presence of serious network problems. These observations show that rating the quality of new multimedia services from the network's side may no longer be effective.

The *user perceived quality of service* (PQoS) field addresses this problem, assessing the quality of a service as perceived by end-users. This seems to be in fact the most coherent approach: after all, the client is who pays for the service and QoS will be what he understands like so, independently of the state of the network that transports the service.

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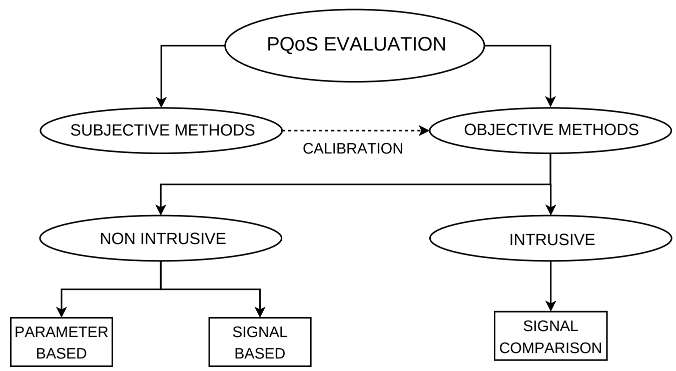

Fig. 1. PQoS Evaluation.

The assessment of perceived quality in multimedia services can be achieved by two different kind of methodologies, either *subjective* or *objective* ones. Figure 1 presents a general overview of PQoS evaluation. Subjective methods define the most accurate metric as they present a direct connection with the user experience. These methods consist on the evaluation of the average opinion that a group of people assign to different audio and video sequences in controlled tests. Different recommendations standardize the most used subjective methods in audio [9] and video [10], [11]. Among them, the MOS (Mean Opinion Score) is by far the most used. In the following section we describe MOS and other different subjective methods. The problem with subjective methodologies is their lack of automation (by definition, they involve a group of people for conducting the tests) resulting in an expensive and time consuming approach.

On the other hand, objective methods do not depend on people, making them really attractive for automating the evaluation process. Objective PQoS measures can be either *intrusive* or *non-intrusive*. In network's context, intrusive means the injection of extra data (audio and/or video streams in multimedia networks, ***signals*** from now on) for performing the measure. Intrusive methods are based on the comparison of two signals, one reference (original) and one distorted (e.g. by the network while transmitted). In general, this comparison is performed either in the time/space domain (simply comparing samples: mean square error (MSE), signal to noise ratio (SNR) or peak signal to noise ratio (PSNR) [1]) or in the *perception domain*, using models of the human senses for improving the results. In this last category we find (for audio assessment) the perceptual speech quality measure (PSQM) [14], the measuring normalizing blocks (MNB) [12], the enhanced modified bark spectral distortion

(EMBSD) [13] and the perceptual evaluation of speech quality (PESQ) [15], [16]; in the case of video, some of the developed tools are the Structural Similarity Index Measurement (SSIM) [19]–[21] and the Institute for Telecommunications Science algorithms, the Video Quality Measurement (VQM) [17] and the Time/Space Structural Distortion Measurement (TSSDM) [**?**]. All these tools provide a measure of the perceptually relevant degradation of the multimedia signal ([22] presents an interesting validation report of objective models for video quality assessment). Bearing in mind their possible application in real-time assessment (a desirable property in todays' networks), the major problem with objective intrusive methodologies is their inherent need of both signals, something that in some scenarios may result too restrictive (however, we will see that in the case of audio this can be somehow solved). In the case of video signals there is an extra problem, the time and resources consumed by complex methods is in general too high.

Non-intrusive methods present an important advantage, they do not require any extra signal for performing the estimation, which allows them to be used in real-time scenarios. Depending on the kind of information they use, non-intrusive methods can be classified as either signal based or parameter based. In the case of signal based methods, the assessment is done without any reference signal, just applying different algorithms to the distorted signal. These methods are also known as "null reference". In the case of parameter based methods, network features as well as characteristics of the multimedia itself are taken as input. The idea is to define a function which maps a PQoS relevant set of these parameters into a quality value (as perceived by the user). Examples of these features are loss probability, loss length (bursty losses), delay, jitter (all of them related to the network), coding, nature of the content (e.g. level of motion, language), bitrate, framerate (related to the signal), etc. The ITU E-Model [7] and the pseudo subjective quality assessment (PSQA) [2]–[4] methods fall into this category. The E-Model is an empirical/mathematical set of formulas originally designed for telephony networks planning, and even though it is actually being used in IP networks, results have shown that it is not still good enough for user perceived quality assessment [6]. The recently introduced PSQA approach uses a statistical learning algorithm (a Random Neuronal Network [5]) to learn the mapping between parameters and user perceived quality. The PSQA has already shown promising results in the PQoS field; in fact, this work was mainly inspired by the results obtained in [2]. The main drawback of parameter-based methods is their strong dependence on subjective tests' results for calibration/training (in fact, all different objective methods must have in some sense a calibration phase as their results are not in the same scale as subjective ones).

The remainder of this paper is organized as follows. In Section II we analyse the measurement methodology of our tool, describing into more detail the algorithms we use. The software implementation is described in Section III, presenting the architecture and it's applications. In Section IV we discuss the experimental results, describing the test environment and comparing the performance of the selected estimation methods. Finally, section V concludes this paper.

II. Measurement Methodology

A. Subjective Evaluation

In this kind of test a group of people is asked for the quality of a group of sequences (audio or video in our case). There are mainly two types of tests in this category, the Absolute Category Rating (ACR) and the Degradation Category Rating (DCR). In a DCR test, people compare the original sequence with the distorted one and then scores the perceived degradation, according to table I. The output of this test is the Degradation Mean Opinion Score (DMOS). In an ACR test, people evaluates only the distorted sequence and scores its quality; in this case the output is the Mean Opinion Score (MOS).

TABLE I
DMOS Quality Scale

Score	Sequence Degradation
5	Imperceptible
4	Perceptible, not annoying
3	Slightly annoying
2	Annoying
1	Very annoying

B. Objective Evaluation

1) Intrusive methods: To measure the PQoS, a multimedia sequence is transmitted through the communication system under study (codec, internet, codec). The resulting distorted signal is then compared with the original one to measure the degradation suffered during transmission. As we have stated before, two kind of comparisons can be performed: direct rough sample comparison (like SNR) are very simple to implement but they are poorly correlated with subjective tests. The comparison can also be done by taking into account a model of human perception to improve the measurement. In this case, the sequences are transformed into a perception domain and then compared, considering only the perceptually relevant distortion.

a) Audio Methods: Three different methods where implemented: Enhanced Modified Bark Spectral Distortion (EMBSD), Perceptual Evaluation of Speech Quality (PESQ-ITU P.862), and Measuring Normalizing Blocks (MNB). Three psychoacoustic concepts are considered in these algorithms:

1) Critical Bands
2) Loudness
3) Masking

The *Critical Bands* are based on the ability of the auditory to distinguish different tones. In low frequencies, a few hertz are enough to distinguish, whereas in high frequencies hundreds of hertz are needed. The auditory system is modeled with a filter bank of band pass filters. The *Loudness* considers the question "how intense is a sound?". For example, a sinusoidal signal of 40 dB at 50 Hz is equally intense to a sinusoid of 0 dB at 1 KHz. The *Masking* concept is the psychoacoustic effect that takes effect when the presence of one sound does not allow the perception of a second one. A typical example of masking can be found in the city, when two people can not hear each other because of traffic. The auditory threshold is modified by the presence of a sound.

2) Video Methods: The considered group of video algorithms differ in what their consider as relevant to the human perception.

a) Time/Space Structural Distortion Measurement - TSSDM: This algorithm was created by the Institute for Telecommunication Sciences, [18]. The target was to create useful metrics for different quality ranges, and at the same time minimize the additional information for the comparison, allowing its use for a real-time point to point quality assessment. To achieve this goals, certain spatial-temporal areas of the video are considered (the same in the original and transmitted) and different parameters are calculated. The algorithm is based on changes in the spatial activity, taking the gradient as a measure of it.

b) Structural Similarity Index Measurement-SSIM: In [19]–[21] a new philosophy in the design of quality metrics was introduced: “The main function of the human visual system is to extract structural information of the viewing field, and the human visual system is highly adapted for this purpose”. These works propose that measurement of the structural distortion should be a good approximation to the perceived distortion. According to [19], structural information is the feature that represents the structure of the objects, independently of the luminance level and contrast of the image.

c) Mean Square Error (MSE) and Peak Signal to Noise Ratio (PSNR): The MSE and PSNR are defined as:

$$MSE = \frac{1}{N}\sum_{i=1}^{N}(x_i - y_i)^2 PSNR = 10Log_{10}(\frac{L^2}{MSE}) \quad (1)$$

where N is the number of pixels in the image or video, x_i and y_i are the i-eth pixel of the original and distorted image respectively, and L is the range of possible values for the pixels (i.e. dynamic range). These quality assessment methods have been the most used ones because of their mathematical simplicity. However, they have been criticised due to their poor correlation with subjective methods.

3) Non-Intrusive Methods:

a) PSQA: As mentioned before, the PSQA method is based on the Random Neuronal Networks (RNN) model. How it works? The results of subjective test (DMOS) depends basically on the state of the transport network (losses, delay, jitter) and the features of the media stream (codec, bitrate, nature of content). If it is possible to estimate the function that maps these parameters into the subjective DMOS, we can approximate the DMOS by measuring these parameters. The RNN are a supervised learning machine, that uses a set of couples *parameters-DMOS* in a training stage to build an approximation to the mapping function. After this stage, the knowledge of the state of the network and the features of the stream are enough to predict the DMOS.

C. Quality Assessment

The developed software tool integrates both intrusive and non-intrusive objective estimation methods. The idea of the tool is not only to perform the PQoS estimation but also to compare the performance of different approaches and algorithms. The chosen algorithms were PESQ, EMBSD, MNB, E-MODEL and PSQA in the case of audio, and MSE, PSNR, SSIM, TSSDM and PSQA for video.

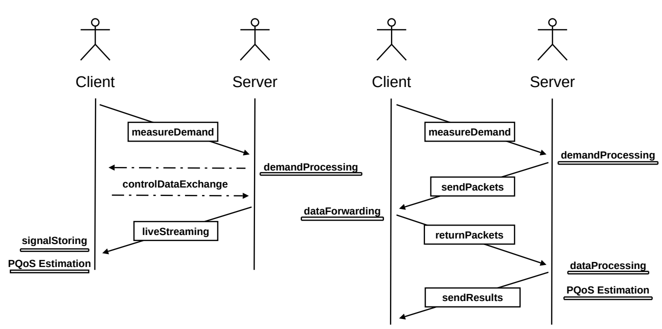

Fig. 2. Measurement methodology

The PQoS evaluation is performed between the extreme points involved in the service for which we want an estimation. The client begins the measurement by sending a demand to the server. Depending on the type of algorithm selected by the client, the server will either send him a reference signal (in real time) of similar characteristics to the actual service (intrusive methods), or start a connection’s parameters estimation via active measurement (non-intrusive methods). If the selected algorithm was intrusive, the client must store the signal sent by the server and perform himself the PQoS estimation (both the client and the server have the same reference signals). In the second case, the server uses the estimated state of the connection (loss probability, jitter, average loss length) plus the corresponding service features (coding, bit-rate, framerate and motion level) as input for performing the estimation. Figure 2 presents a brief summary of both possibilities. Tasks’ synchronization between extreme points is achieved by means of a communication protocol, specially developed for this tool.

III. Software Implementation

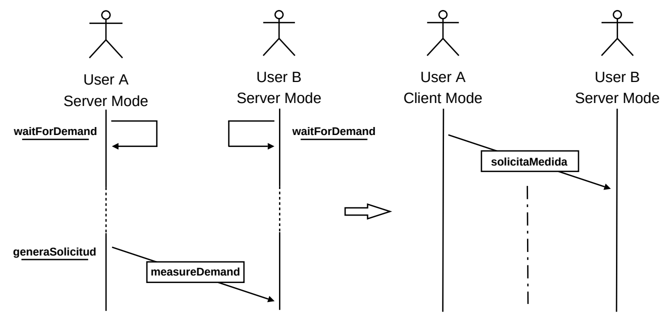

Fig. 3. Symmetrical architecture

The PQoS estimation software tool was designed to be used in both end-points of the service at the same time. The architecture foresees a symmetrical operation, in which both end points can work as either clients or servers (considering the classical client/server paradigm, where the client asks for some service and the server responds to his demands). Figure 3 explains this concept of symmetry. At the very beginning, both extreme points act as servers, waiting for a PQoS evaluation demand from the opposite side. When one of both machines decides to perform an estimation, the scheme changes to a traditional client/server one, coming to the previously explained operation case (figure 2). The main advantage of this symmetrical architecture is the ability that both end-points acquire to process and generate information, saving transmission and operation time.

A. Software Design

During the software design phase, special attention was directed to the modularity of the tool. The key idea was to conceive a reusable and easily to improve/modify design. The final implementation resulted in a 5 independent module design (each of them can be used isolated from the rest, in any other application). Figure 4 presents a general overview of these 5 modules. The ***System Manager*** is the software’s brain. It manages the connection establishment and data exchange between end-points as well as the rest of the different modules. It is basically composed of 3 sub-modules: a *client*, a *server* and the *manager* itself. The ***PQoS Algorithms*** module is the most important module of the system, as it implements the different estimation algorithms so far discussed. The ***Sequences Provider*** module supplies the audio and video signals for intrusive PQoS estimation. It consists of an audio streaming platform (implemented with the Java Media Framework toolbox, [24]), a video streaming platform (implemented with the Video Lan Client project, [25]) and a reference signals database. The ***Network Estimator*** module is in charge of the network parameters estimation. For doing so, it uses both end-points of the connection to send and receive probe packets. Finally, the ***GUI*** module implements the graphical user interface to easily interact with the tool. The programming language of the toolbox is not the same for all the modules. Higher layer implementations where mostly developed in Java, while lower layer programming (C and C++) was used in almost all critical time applications (e.g. PQoS intrusive algorithms). The interaction between languages was achieved by using the Java Native Interface library, a versatile set of classes/functions which aloud the communication between both “worlds”.

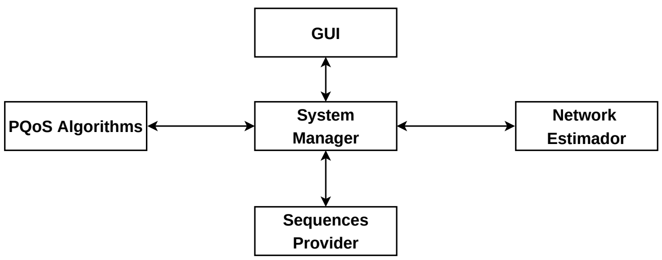

Fig. 4. Software components.

IV. Experiments and Results

A. The Test Bed

To perform the subjective tests, calibrate the objective methods and evaluate the performance of the different approaches we developed a simple test bed which allows to emulate network conditions in a controlled fashion [1]. This test bed is composed of two end point machines (server/client) connected through an intermediate router that simulates losses, delay and jitter. In the case of losses, a markovian Gilbert loss model is applied in order to generate bursty losses [23]. Jitter and delay are controlled by direct manipulation of buffers.

The multimedia signals’ sets consisted on 75 original-distorted couples for video and 72 couples for audio. The reference video sequences where chosen according to the reference [10], [11] (40 short sequences of 10-30 seconds, good lighting level, etc.) and classified by coding (MPEG1 and MPEG4) and motion level (low, medium and high). In audio, 24 short sequences where recorded and coded with three different codecs (PCM, GSM and G.723). Each reference signal was transmitted through the test bed, setting different values for the router’s parameters so as to cover the most suitable ones of an Internet like scenario (i.e. 75 different parameters’ combinations in video and 72 in audio). The generated signals were then used for conducting the subjective tests (as described in section II), resulting in a final data set of the form

$$\left(sc\left(j\right), \{p_0, p_1, .., p_i, .., p_n\}, DMOS\right), \qquad (2)$$

where $sc\left(j\right)$ is the j-th original-distorted signal couple, p_i is the value of the i-th parameter (e.g. loss probability, burst length, jitter, codec, level of motion, etc..) and *DMOS* is the corresponding subjective test result. Finally, part of the data set was used to train the PSQA learning algorithm and calibrate the objective intrusive methods, using the remaining data for validation.

B. Evaluation of the Different Techniques

In order to compare the performance of the different algorithms we use a traditional error estimator, the mean absolute error (MAE), between estimated values (algorithms) and real ones (subjective tests). As stated in section I, intrusive methods’ results are not in the same scale as DMOS values (they are correlated with human assessment but each one uses its own scale), so a calibration phase is conducted before the comparison (except for PESQ which is already calibrated). As regards non-intrusive algorithms (we will only consider PSQA in the evaluation, the E-Model has already shown poor performance [1], [6]), the system must be trained before applying it. In both cases we split the previous data set in a *training data set* (70%) and a *validation data set* (30%). With the first set we calibrate/train the intrusive/non-intrusive methods, with the second we do the validation.

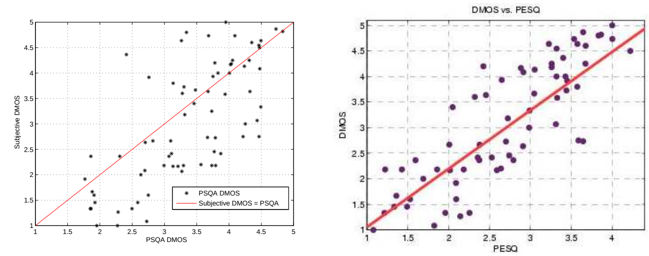

Fig. 5. DMOS vs PSQA (left) and DMOS vs PESQ (right)

TABLE II
Mean Absolute Error (MAE) and Correlation Factor (CF)

Method	MAE	CF
EMBSD	0.77	0.77
PESQ	**0.43**	**0.88**
MNB	0.66	0.71
PSQA	0.70	0.79

1) Audio analysis: Figure 5 presents the results obtained with PSQA (left) and PESQ (right) with the whole data set (in fact, the training data set was used with PSQA but all samples were used for validation). In the case of audio we have decided to present the graphical results of the best intrusive method (between PESQ, MNB and EMBSD) and the non-intrusive one (PSQA); all results can be found in [1].

In table II we present the actual values of the MAE for all algorithms, including as well the Correlation Factor (CF) between real and estimated DMOS (a value close to 1 indicates high linear correlation)

The results obtained in audio quality assessment presents the PESQ intrusive method as the best. Compared with the other intrusive ones, PESQ has a major advantage: it includes a temporal re-synchronization algorithm that allows an accurate signal comparison. In the presence of data losses, a direct signal comparison may result in very poor performance (worst results are obtained as losses occur closer to the beginning, see [1]). It is important to recall that PESQ is the actual ITU recommendation for voice perceived quality assessment ([15]). Results obtained in our test bed with ***our implementation*** of PSQA denote a lack of adaptability of the RNN to the used data set. During subjective tests we realized that people’s reactions to impairments in data voice are very different (in fact, post-test data analysis showed big variance of results), resulting in a difficult data space mapping.

2) Video analysis: In video analysis, ***our implementation*** of PSQA is clearly the best method, and not only because of the smallest error value, but mainly because of the time involved in the estimation. Table III summarizes these observations. Figure 6 shows the different

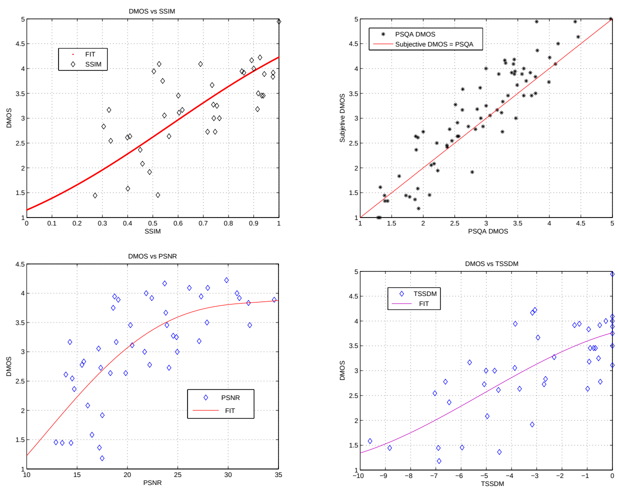

Fig. 6. Upper left DMOS vs SSIM, upper right DMOS vs PSQA, lower left DMOS vs PSNR, lower right DMOS vs TSSDM

algorithms along with their respective fit curves (in the case of PSQA a straight line $SubjectiveDMOS = PSQA$ is plotted to see the quality of the results).

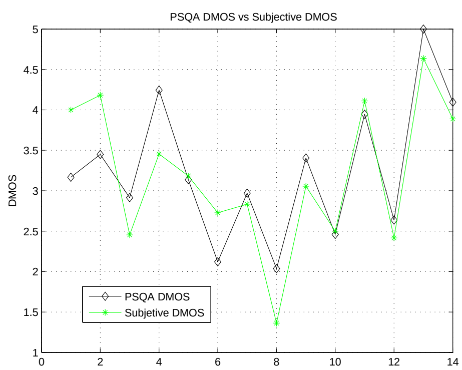

Fig. 7. Subjective DMOS and PSQA - validation date set

As stated in section II, in the case of video there are no standardized methods for perceived quality assessment, something that shows that PQoS for video is still a very difficult problem. The intrusive methods presented in this work suffer from the same synchronization problem as in the audio case. However, the performance obtained by PSQA shows a priori that the problem can be solved. To conclude with video analysis, we show in figure 7 the results obtained by PSQA in the validation data set.

3) Analysis of the influence of through PSQA: One interesting advantage of objective parameter based algorithms is the possibility to analyse the influence of different features over PQoS. Figure 8 presents the influence of voice codec selection (left) and video motion level (right) on perceived quality as a function of loss probability. As expected in audio, losses in the case of *G.711* coding (pure PCM, bigger bitrate, no predictive model seriously affected by losses) are less annoying. In the case of video is also clear that losses on faster scenes bother more.

Finally, figure 9 evidences the influence of bursty losses over voice (left) and video (right) perceived quality. It is interesting to see in both

TABLE III

MAE AND AVERAGE COMPUTING TIME (ACT)

Method	MAE	ACT (seconds)
SSIM	0.60	> 600
PSNR	0.48	≈ 20
PSQA	**0.40**	$\approx$ **1**
TSSDM	0.53	> 1200

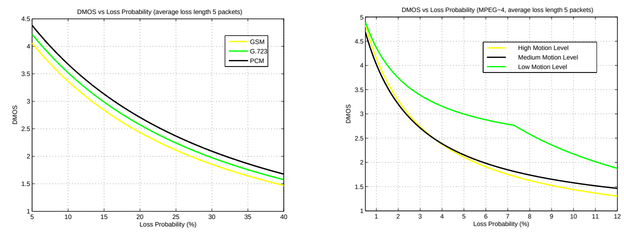

Fig. 8. DMOS vs loss probability for different audio codecs (left) and different video motion levels (right)

cases that, in the case of high loss probability (20% in audio, 3% in video) isolated losses have a stronger impact over PQoS than bursty ones (this is because isolated losses must occur more frequently than bursty ones to keep the same loss probability).

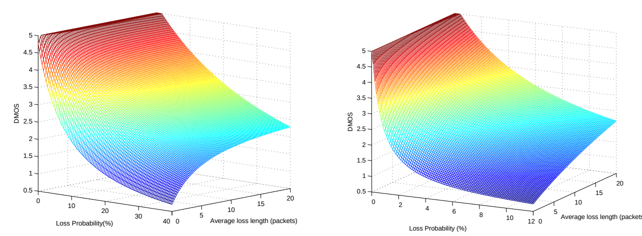

Fig. 9. DMOS vs loss probability and average loss length for audio (left) and video (right)

V. CONCLUSION

In this paper we have presented the Quality of Service problem from an end-user point of view. Different methodologies have been introduced for quality assessment in multimedia services. An original software tool for PQoS evaluation has been developed and described in this work. The main advantages of this tool are the combination of a broad set of the different methodologies that have been proposed to the date, the integration of all the aspects related to the automation of the estimation process and its modular design. We use the software tool for comparing the performance of the different methods considered and we present experimental results in a real simulation test bed. There are still many possible improvements for the estimation tool and for the experimental results that were obtained. In particular, experiences should be carry out in a more general Internet like environment to validate the implementation and to continue with the PQoS analysis.

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