This full text paper was peer reviewed at the direction of IEEE Communications Society subject matter experts for publication in the ICC 2008 proceedings.

Fast and accurate PQoS estimation over 802.11g wireless network

Pasquale Pace, Marco Belcastro, Emanuele Viterbo

DEIS - University of Calabria, Rende, ITALY
Email: (ppace, viterbo)@deis.unical.it

***Abstract* — The deployment of WLAN-based solutions for efficient distribution of multimedia content over wireless links is rapidly increasing in the last few years. Nevertheless many performance issues concerning the delivery of high bit rate stream-oriented content using current IEEE 802.11 standards and the measurements of the customers satisfactions in terms of perceived quality, are still open and of great interest.**

This paper proposes a simple curve fitting technique for estimating, in a fast and accurate way, the perceived quality of streaming media contents delivered within a wireless network. The model accounts for the effects of various network parameters such as congestion, radio link power and video transmission bit rate. The correctness of the designed model has been verified through many different measurements in realistic wireless environments through an ad-hoc test bed.

Index Terms - Perceived quality of service, MPEG, subjective video quality assessment, video scaling.

I. Introduction

It is well known that the goal of any QoS mechanism is to maintain a good level of user-perceived QoS even when the network conditions are constantly and unpredictably changing.

Typical QoS provisioning solutions for multimedia video applications have been always based on the idea of trying to reserve or assure certain network guarantees, so that packets coming from delay or bandwidth sensitive applications receive a better treatment in the network. This approach has been demonstrated to work very well in fixed networks. However, in wireless networks it is not always possible to offer any guarantee, due to continuously changing conditions and unpredictable radio link consumption.

Fluctuations in network resource availability due to channel fading, variable error rate, mobility, and handoff, makes QoS provisioning more complex in wireless networks. Moreover, determining how exactly network congestion manifests itself in degraded stream quality is still a challenging problem. Understanding the relationship between stream quality and network congestion is an important step to solving this problem, and can lead to better design of streaming protocols, computer networks, and content delivery systems.

An alternative way for providing the agreed quality of service is to estimate the PQoS (*Perceived Quality of Service*) index with the aim of making the best scaling for the video content also achieving the "*golden selection*" between quality of service, bandwidth availability, bit rate and frame transmission rate.

The objective quality perceived by the non-expert user can be measured with purely subjective criteria, as opposed to the Network QoS, which relies on objective measurable parameters (throughput, BER etc.). A complicating factor is the individual nature of how users evaluate the quality that they receive. Any two users who may be sharing a common experience (i.e. identical applications) are likely to have significantly different views of the QoS; thus, the important thing is to understand how such individual views are used for estimating the connection between wireless network parameters and user perception of QoS provided over that network.

This link will typically take the form of a numerical mapping (mathematical relation) between some measure of the user-perceived quality (e.g. the *Mean Opinion Score* (MOS)[1]) and a particular set of network parameters (e.g. available bandwidth).

Typically, the five-point scale MOS is used to collect feedback from end users on the subjective quality of a media stream. However, assessments of subjective quality are time consuming and expensive; furthermore, they cannot be easily and routinely performed for real time systems. Accordingly, there is the need for a quality metric that accurately matches the subjective quality and can be easily implemented in real-time video systems. In particular, objective metrics would be of great benefit to applications involving scalable video coding and multi-dimensional bit rate control used in mobile video broadcasting systems.

This work presents several key contributions. First we set up an ad-hoc testbed for evaluating the perceived video quality of multimedia contents transmitted over a wireless network using the well known VQM objective metric [13][14]. Second, we examine how network parameters such as congestion, signal power level and transmission bit rate affect streaming media and video data that are sent on demand over the wireless network from a single server center to one or more users equipped with a handheld device. Third, we design an accurate analytical model for "*real-time estimation*" of the perceived quality according to the network and video parameters. Finally we verify the correctness of the propose model in several network conditions.

Thanks to this model we can estimate the PQoS of each video and we can rapidly adapt the transmission of the content through scalable video coding and multi-dimensional bit rate techniques in order to offer the best quality to the end users. Thus, it could be possible to implement and use "*adaptive applications*" as a complement to the traditional network–layer reservations. So, whenever the network resources become scarce and the QoS guarantees are violated, the applications can self-adapt the internal settings (e.g. frame rates, video sizes, etc.) reducing the data rates to those that the network can support in that precise moment always guaranteeing a good PQoS value.

II. Related Work and Literature

Some quality metric evaluations have been conducted in the last years. Although *Feghali et al.*[2] proposed a new quality metric for filling the gap between the classical PSNR and the subjective quality metrics, they do not consider other network-level parameters as the wireless link power and the effect produced by other data traffic on the same link. In [3] the authors study the user's perception of multimedia quality, when impacted by varying network-level parameters as delay and jitter, however they use subjective quality metrics that are very expensive and time consuming. The paper [4] presents a method for objective evaluation of the perceived quality of MPEG-4 video content, based on a quantification of subjective assessments. Showing that subjectively derived perceived quality of service (PQoS) vs. bit rate curves can be successfully approximated by a group of exponential functions, the authors propose a method for exploiting a simple objective metric, which is obtained from the mean frame rate vs. bit rate curves of an encoded clip; even in this work no network-level parameters have been considered.

In our work, we estimate the perceived quality value according to the bit rate of the transmitted video, the signal power level and the data traffic on the wireless link. We design a model that closely approximates VQM objective metric behavior when the above parameters vary. Thanks to the proposed model, the evaluation of the PQoS is extremely easy and fast making the tool suitable for scalable video coding and multi-dimensional bit rate in mobile wireless video applications.

III. Perceived Quality Meter Methods and Recommendations

Over the last years, emphasis has been put on developing methods and techniques for evaluating the perceived quality of digital video content. These methods are mainly categorized into two classes: The *subjective* and *objective* ones.

The subjective test methods involve an audience of people, who watch a video sequence and score its quality as perceived by them, under specific and controlled watching conditions.

The following opinion scale employed in an ACR (Absolute Category Rating) test is the most frequently used in ITU-T [1]: excellent (5), good (4), fair (3), poor (2), and bad (1). The arithmetic mean of all the opinion scores collected is the MOS.

The best known subjective techniques for video are the *Single Stimulus Continue Quality Evaluation (SSCQE)* and the *Double Stimulus Continue Quality Evaluation (DSCQE)* [5], [6]. The fact that the preparation and execution of subjective tests is costly and time consuming deprives their use in commercial mobile systems, which aim at providing audiovisual services at predefined quality levels.

The objective methods are characterized and categorized into classes, according to the procedure of the quality evaluation.

One of these classes requires the source video sequence as a reference entity in the quality evaluation process, and is based on filtering the encoded and the source sequences, using perceptual filters (i.e. Sobel filter). Then, comparison between these two filtered sequences provides results, which are exploited for the perceived quality evaluation [7], [8].

Another class of objective evaluation methods is based on algorithms, which are capable of evaluating the PQoS level of the encoded test sequences, without requiring any source video clip as reference.

A software implementation, which is representative of this non-reference objective evaluation class, is the *Quality Meter Software (QMS)* [9]. The evaluation algorithm of the QMS is based on vectors, which contain information about the averaged luminance differences of adjacent pixels.

For all previous reasons, a lot of effort has recently been focused on developing cheaper, faster and easily applicable objective evaluation methods, which emulate the results that are derived from subjective quality assessments, based on criteria and metrics, which can be measured objectively.

Due to the subjective methods limitations, engineers have turned to simple error measures such as mean squared error (MSE) or peak signal to noise ratio (PSNR), suggesting that they would be equally valid. However, PSNR does not take into account human vision and thus cannot be a reliable predictor of perceived visual quality.

Starting from all the previous considerations, a considerable amount of recent research has focused on the development of quality metrics that have a strong correlation with subjective data. Three metrics based on models of the Human Visual System (HVS) are summarized in [10]: the Sarnoff Just Noticeable Difference (JND) model, the Perceptual Distortion Metric (PDM) model developed by Winkler [11] and Watson's Digital Video Quality (DVQ) metric [12]. Finally, a general purpose video quality model (VQM) was standardized by ANSI in July 2003 (ANSI T1.801.03-2003), and has been included in Draft Recommendations from ITU-T Study Group 9 and ITU-R Working Party 6Q.

The General Model was designed to be a general purpose video quality model (VQM) for video systems that span a very wide range of quality and bit rates, thus it should work well for many other types of coding and transmission systems (e.g., bit rates from 10 kbits/s to 45 Mbits/s, MPEG-1/2/4, digital transmission systems with errors).

This model has been shown by the Video Quality Experts Group (VQEG) [13] in their Phase II Full Reference Television (FR-TV) test to produce excellent estimates of video quality for video systems; the model obtained an average Pearson correlation coefficient over tests of 0.91 [14]; to the best of our knowledge, VQM is the only model to break the 0.9 threshold for this reason we chose to use it in our work as reference model for PQoS estimation.

IV. System Architecture and Testbed Deployment

In this section we describe the network architecture used for evaluating the perceived quality of the transmitted multimedia contents. We recorded several video clips with different bit rates; we used the digital video encoding formats MPEG-4 [15] because it is mostly preferred in the distribution of interactive multimedia services over IP; furthermore, MPEG-4 is also suitable for 3G networks providing better encoding efficiency at low bit rates, compared to the previous formats (MPEG-1, MPEG-2).

The network architecture is shown in Fig. 1; it is composed by both wired and wireless segment. The service center belongs to the wired segment and has the task of sending multimedia contents to the wireless clients (e.g. Laptop, PDA, smartphone, see-through glasses for augmented reality etc…). On the wireless segment the transmission of multimedia contents can take place in both directions, from the clients to the access point (AP) and vice versa. This architecture can be used to provide real time video with augmented reality: a classical example is offered by a client device equipped with a wireless camera that can be used by a visitor inside a museum; the camera can record and send the video of the ambient in which the visitor is walking to the service center that is in charge of locating the client and send him multimedia contents regarding the paintings or the art work recorded in the video previously sent. A similar service can be offered in an archaeological site to supply augmented reality area wireless network.

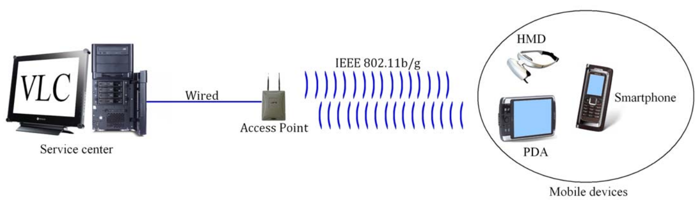

Fig.1 Simple system architecture.

In order to emulate the previous scenario, we used different multimedia videos transmitting them from the wireless mobile device on the right side of the Fig. 1, to the service center and vice versa using VLC[1] [16], a powerful software well suited for video streaming.

Each video clip was transcoded to MPEG-4 format, at various variable bit rates (VBR) according to the mean data rates shown in Table I. Resolution (320×240) and constant frame rate of 25 frames per second (fps) were common parameters for the transcoding process in all test videos. These video parameters are typically supported by handheld mobile devices.

With the aim of implementing a more realistic scenario, we considered also the data traffic generated from other mobile devices within the AP coverage area. This aggregated data traffic represents a set of different applications such as download of audio-video contents, text files or web surfing; it can be considered as "*background traffic*" handled by the access point without stringent delay constraints, nevertheless the amount of this background data traffic has, for sure, a heavy impact on the multimedia video transmission in terms of perceived quality, thus the evaluation of the PQoS metric and the resulting analytical models cannot be designed without considering this kind of traffic.

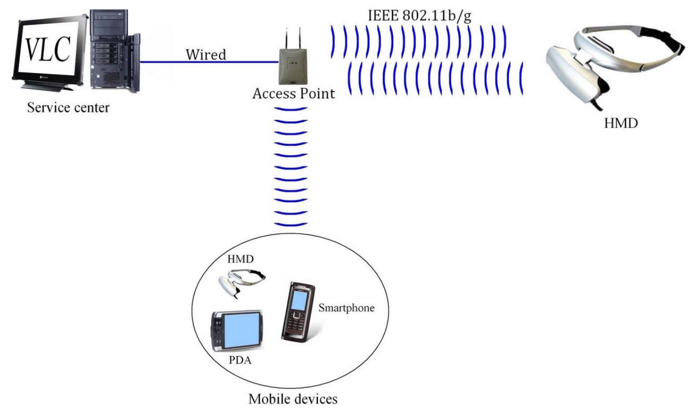

Fig. 2 The whole system architecture.

The whole system architecture is shown in Fig. 2, we used another laptop for generating the aggregated background traffic; moreover, we gradually increased the amount of generated data traffic in order to study the effect on the perceived quality during the transmission on the wireless channel.

Concerning the background traffic values for the whole simulation campaign, the following remark is appropriate. We implemented a wireless IEEE 802.11g [17] network, that can support nominal data rate up to 54Mbps; yet, in practice only half of the advertised bit rate can be achieved because wireless networks are particularly error-prone due to radio channel impairments, the data signals are subject to attenuation with distance and signal interference. In addition, the transmission quality is also affected by contention between users who are attempting to access and transmit data on the shared radio channel. This contention results in users having to wait until their backoff process is complete, before they can access the channel.

We observed, through few simple tests, that the perceived video quality is not degraded if the traffic background is smaller than 11Mbps; this performance is due to the high link capacity supported by the specific AP[2] .

We experimented that 28Mbps is the maximum background traffic sustainable by our wireless network.

Table I summarizes all the system parameters used for the testbed; the transmitted multimedia video have been recorded with several bit rate values to satisfy different applications requirements; furthermore, we evaluated the system performance varying the wireless link quality in terms of signal power level. Using *Network Stumbler* [18] we obtained the values of signal power level over the wireless link in a very accurate way depending on the distance from the access point. For each parameter combination we took several samples repeating the perceived quality measurement 8 times with the aim of considering the natural wireless link and background traffic fluctuations.

In order to measure the video quality over the wireless

[1] *VideoLAN* is a software project, which produces free software for video, released under the GNU General Public License. VLC media player is a free cross-platform media player, it can be used as a streaming server, with extended features (video on demand, on the fly transcoding, ...)

[2] The AP used for the testbed is a USRobotics® Wireless MAXg Router 5461A.

network we used MSU [19]. This free program has many interesting features to evaluate the video quality according to several metrics (i.e. PSNR, DELTA, MSAD, MSE, SSIM and VQM) and the obtained results are collected in a .CVS file thus they can be easily handled through any spread sheet.

During the transmission over the wireless link, few frames can be lost due to low signal level or to high interference conditions; nevertheless the software used for the PQoS evaluation needs to compare two videos with exactly the same number of frames, thus we implemented a realignment procedure for replacing the lost frames with the last frame correctly received in order to obtain a consistent analysis.

TABLE I. SYSTEM TRAFFIC PARAMETERS.

Video bit rate	Background traffic	Signal power level over wireless link
2350 Kbps	5 Mbps	-15dBm (excellent)
1870 Kbps	11 Mbps	-40dBm (good)
1470 Kbps	22 Mbps	-66dBm (fair)
810 Kbps	26 Mbps	-76dBm (poor)
450 Kbps	28 Mbps	

TABLE II. VQM MEASURED VALUES AT -15DBM.

Background Traffic	Video Bit rate				
	450 Kbps	810 Kbps	1470 Kbps	1870 Kbps	2350 Kbps
0 Mbps	0,6452	0,5405	0,3552	0,3625	0,3246
5 Mbps	0,6452	0,5475	0,3552	0,3741	0,3439
11 Mbps	0,6452	0,5546	0,3552	0,3857	0,3632
22 Mbps	0,6927	0,5990	0,8080	0,9838	1,2077
26 Mbps	0,8197	0,6737	1,1294	1,6501	2,4743
28 Mbps	0,9212	0,7346	1,5547	2,1475	3,2797

V. TEST BED RESULTS AND ANALYTICAL MODEL

In this section we show the results in terms of perceived video quality, obtained from the test bed varying the network parameters and we propose a simple analytical model for estimating the perceived quality.

The designed model is well suited and detailed for the proposed wireless architecture but it can be valid for every general wireless network architecture. Our model is based on simple parameters that can be easily computed in a first "*training phase*". The implementation of an integrated software for the perceived quality measurement of few video contents, and the resulting calibration of the polynomial model coefficients, is quite simple. In this way, the analytical model plays a primary role in the PQoS estimation and the consequent real-time video scaling or format adaptation.

A. Fixing the wireless link quality

First of all we fixed the power level of the wireless signal to the best value (i.e. -15dBm) in order to study the system performance in a very good condition in which the interference has a negligible effect; in this way the perceived video quality is strictly linked only to the background traffic and the bit rates; the following analysis is oriented to discover the relationship between those two system parameters. Fig. 3 shows how the perceived quality decreases when both, the background traffic and the bit rate of the transmitted video, increase. Furthermore, background traffic values smaller than 11Mbps do not influence the perceived quality index. Choosing an objective VQM value for each video, an accurate scaling can be done according to the trend of those curves. Table II summarizes all the measured quality values that will be used for the analytical model fitting.

A natural conclusion of this first test is that the videos with a higher bit rate feel the effect of the background traffic in a pronounced way. Thus, loading the channel with low data traffic, the perceived quality is reduced transmitting videos with small data rate; on the contrary, loading the channel with high data traffic it is better to send videos at low bit rate.

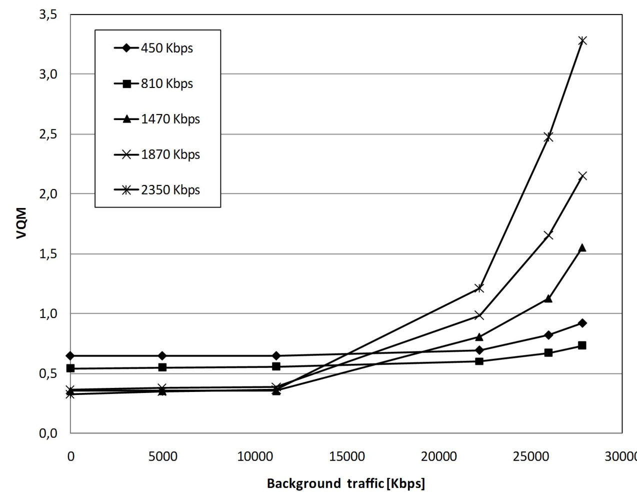

Fig. 3. Perceived quality vs. video bit rates with different background traffic.

B. Varying the wireless link quality

The link quality is for sure one of the most important parameters in the evaluation of standard QoS index in wireless networks. Its contribution in terms of PQoS is still an open and challenging issue that we consider in this section. Fig. 4 shows the perceived quality index with different values of signal strength over the wireless link. This measurement has been carried out by fixing the background traffic value to 11Mbps in order to study the signal power level effect in a mean working condition in which the background traffic presence can not drastically affect the contribution of the signal power level. When the measured power level from the receiver is very low (i.e. -76 dBm) the VQM index does not depend by the video bit rate, in fact that curve fluctuates round 1.5 VQM value; thus in this condition, a video with low bit rate has almost the same quality of a video with high bit rate.

In the other two cases (i.e. -66 dBm and -46 dBm) the slight decrease of the VQM value is more evident on videos with higher bit rate.

Following the previous considerations we can argue that the signal power level over the wireless link is weakly related to the video bit rate and the background traffic. For this reason we can treat the weight of the power level over the link as an additive value according to the trend in Fig. 5. Thanks to the measurements carried out through the testbed we can approximate the trend of the curve with polynomial equation that will be used for designing the analytical model.

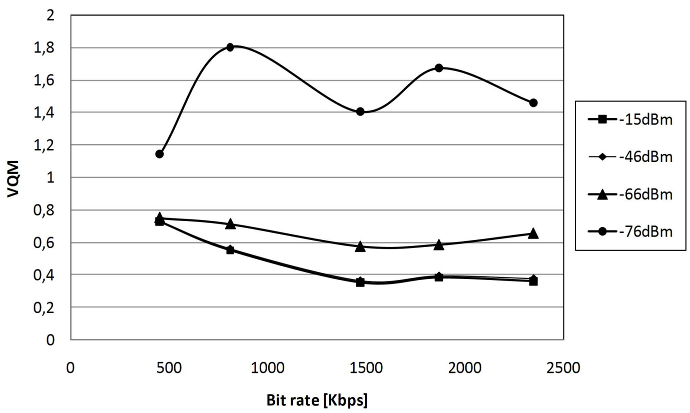

Fig. 4. PQoS varying the quality link and the bit rate.

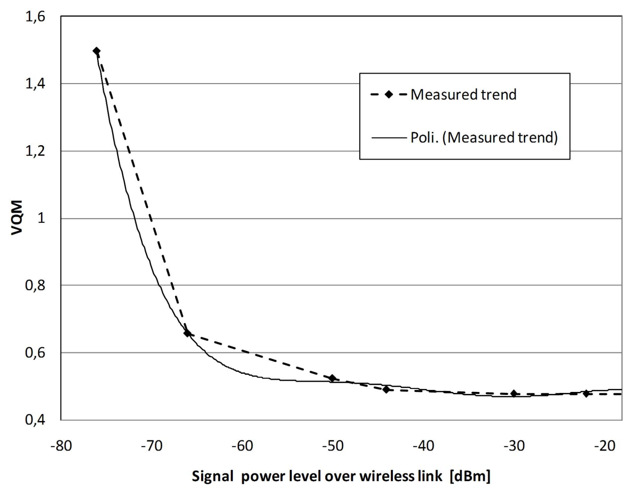

Fig. 5. PQoS varying the link power level.

C. Analytical model for estimating the PQoS value

The main goal of this section is the design of an analytical model in which all the previous PQoS measurements for our wireless network can be mixed in order to obtain the VQM value in a fast, responsive and reliable way. According to the curves presented in Fig. 3 we pointed out the relations between the video bit rates and the background traffic; now we need to find a mathematical relation that can represent the trend of those curves.

As we already explained, the perceived quality is considered in our work as a function of three parameters: the video bit rate *R*, the background traffic *B* and signal power level over the wireless link *C*. Thus the PQoS can be expressed through the following relation:

$$PQoS = g(R, B, C) \tag{1}$$

For sake of simplicity we used the normalized version of those quantities according to the following formula

$$x = \frac{X - mean(X)}{std(X)} \tag{2}$$

where *mean(X)* and *std(X)* are the mean and the standard deviation of the measured quantities *X=(R,B,C)*; thus we have

$$PQoS = h(r, b, c)$$

(3)

As already explained in this section, the signal strength over the wireless link is not strictly related with the video bit rate and the background traffic; for this reason treating the wireless link power as an additive value we can re-write the relation (3) as sum of two different functions

$$PQoS = h(r,b,c) = f_1(r,b) + f_2(c) \tag{4}$$

Thanks to the measurements carried out through the test bed, we can fit both f_1 and f_2 functions by using two polynomials that approximates those functions.

$$\begin{aligned} P_1(x,y) &\cong f_1(r,b) \\ P_2(z) &\cong f_2(c) \end{aligned} \tag{5}$$

where

$$P_1(x,y) = \sum_{i=0}^{n-1} \sum_{j=0}^{m-1} a_{ij} x^i y^j = \sum_{k=0}^{m-1} \alpha_k(x) y^k = \sum_{k=0}^{n-1} \beta_k(y) x^k \tag{6}$$

$$P_2(z) = \sum_{k=0}^{v-1} c_k z^k \tag{7}$$

In our study we used (*m*=6) different values for background traffic and (*n*=5) different values for video bit rate, thus we implemented a linear system of 30 equations in the unknowns a_{ij} for the polynomial P_1 whilst we used (*v*=4) values for the power level over the wireless link (i.e. Table I) corresponding to a 4 equations linear system in the unknowns c_k for the polynomial P_2. Thanks to the proposed model we can easily evaluate the performances of different scenarios through a coloured scale representing the good mix (green and light green-areas) and the bad mix (red and dark-red) of system parameters in terms of perceived quality values. Many interesting considerations can be made observing Fig. 6 because the relations between all the system parameters involved in the evaluation of the PQoS are mixed together through numerical connections.

D. Testing the quality of the analytical model

In this section we demonstrate the reliability of the proposed model showing the correlation between the measurements executed with MSU software and the results obtained through the analytical framework. For supporting this analysis we recorded new videos with different parameters according to Table III.

The obtained results are summarized in Table IV; as we can see, the difference between the two approaches is a negligible quantity. The overall Pearson linear correlation coefficient between VQM quality and analytical model for the video sequences is equal to 0.986 making the proposed model very truthful. We did not show the results for others signal power level values due to the lack of space, however we tested the system in many different conditions in order to verify the model correctness.

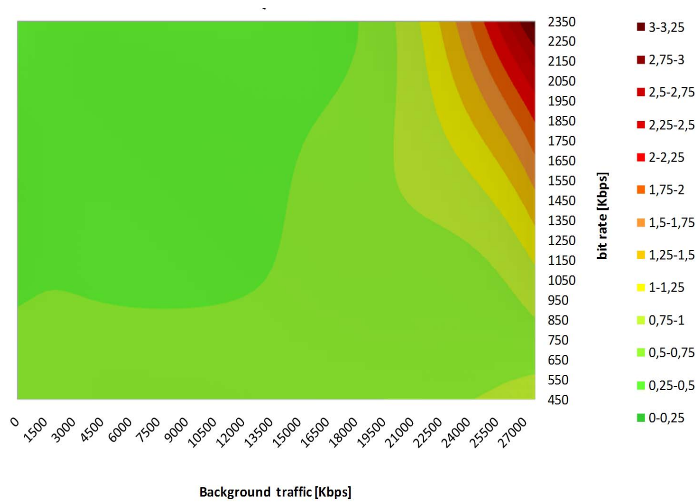

Fig. 6. PQoS map obtained from the analytical model at – Signal Power Level -15dBm.

TABLE III. VIDEO PARAMETERS FOR TESTING THE ANALYTICAL MODEL.

Background Traffic [Kbps]	Bit rate [Kbps]	Signal power level [dBm]
14300	630	-15
18560	1000	-15
24160	1560	-15

TABLE IV. VQM VALUES MEASURED THROUGH MSU SOFTWARE VS. PQOS VALUES ESTIMATED WITH THE ANALYTICAL MODEL.

Measured values using MSU				
		Background Traffic [Kbps]		
Bit rate [Kbps]		***14300***	***18560***	***24160***
	630	0,569878	0,61557	0,653899
	1000	0,539471	0,592827	0,694409
	1560	0,4555	0,561323	1,031743
Estimated values using the Analytical model				
		Background Traffic [Kbps]		
Bit rate [Kbps]		***14300***	***18560***	***24160***
	630	0,609	0,608	0,647
	1000	0,497	0,535	0,676
	1560	0,415	0,552	1,023

VI. CONCLUSION

In this paper we have measured the perceived quality of multimedia video contents transmitted over wireless LAN based on the IEEE 802.11g standard. We studied the effects of network parameters on the PQoS index highlighting the connections between them. Finally we designed an analytical model for estimating the PQoS index in a fast and easy way. The proposed analytical model has obtained an average Pearson correlation coefficient of 0.986, as proof of its robustness and reliability.

REFERENCES

[1] ITU-T Recommendation P.910, “Subjective video quality assessment methods for multimedia applications,” Recommendations of the ITU, Telecommunications Sector.

[2] R. Feghali, et al. “Video Quality Metric for Bit Rate Control via Joint Adjustment of Quantization and Frame Rate,” IEEE Transaction on Broadcasting, Vol. 53, no. 1, march 2007, pp. 441-446.

[3] S. R. Gulliver and G. Ghinea “The Perceptual and Attentive Impact of Delay and Jitter in Multimedia Delivery,” IEEE Transaction on Broadcasting, Vol. 53, no. 2, june 2007, pp. 449-458.

[4] H. Koumaras, A. Kourtis, and D. Martakos “Evaluation of Video Quality Based on Objectively Estimated Metric,” Journal of Communications and Networks, Vol. 7, no. 3, September 2005, pp. 1-8.

[5] “Methology for the subjective assessment of the quality of television pictures,” Recommendation ITU-R BT.500-10 ITU, Switzerland, 2000.

[6] T. Alpert, L. Contin, “DSCQE Experiment for the Evaluation of the MPEG-4 VM on Error Robustness Functionality,” ISO/IEC – JTC1/SC29/WG11, MPEG 97/M1604, February 1997.

[7] S. Wolf, M. H. Pinson, “In-service Performance Metrics for MPEG-2 Video Systems,” Measurement Techniques of the Digital Age Technical Seminar, Montreux, Switzerland, November 12-13, 1998.

[8] S. Wolf, M. H. Pinson, “Spatial – Temporal Distortion Metrics for in-service Quality Monitoring of any Digital Video System,” SPIE International Symposium, Boston, MA, September 11-22, 1999.

[9] J. Lauterjung, “Picture Quality Measurement,” IBC Amsterdam September 1998.

[10] Z.Yu, H.R.Wu, “Human Visual System Based Objective Digital Video Quality Metrics,” Proceedings IEEE Int. Conf. on Signal Processing, 2000, Vol. 2, pp. 1088-95.

[11] S. Winkler, “A Perceptual Distortion Metric for Digital Color Video,” Proceedings SPIE Human Vision and Electronic Imaging IV, San Jose, January 1999, Vol. 3644, pp. 175-84.

[12] A.B. Watson, “Toward a Perceptual Video Quality Metric,” Proceedings SPIE Human Vision and Electronic Imaging III, 1998.

[13] Final Report from the Video Quality Experts Group on the Validation of Objective Models of Video Quality Assessment, Phase II [Online]. Available: www.vqeg.org

[14] M.H. Pinson, S. Wolf, “A new standardized method for objectively measuring video quality,” IEEE Transactions on Broadcasting, Vol. 50, Issue 3, Sept. 2004, pp.312-322.

[15] ITU-T Rec. H.264/ISO/IEC 14496-10 AVC, JVT-G050, Joint Video Team (JVT) ISO/IEC MPEG, ITU-T VCEG, “Final Draft, International Standard on Joint Video Specification” 2003.

[16] VideoLAN. Developerd by students of Ecole Centrale Paris. [Online] www.videolan.org.

[17] D. Vassis, G. Kormentzas, A. Rouskas, I. Maglogiannis, “The IEEE 802.11g standard for high data rate WLANs,” IEEE Network, Vol. 19, Issue 3, May-June 2005, pp. 21-26.

[18] M. Milner, NetStumbler 0.4.0. [Online] 2004. www.stumbler.net.

[19] MSU Video Quality Measurement Tool. [Online] http://www.compression.ru/video.