Cross–Layer Adaptation of H.264/AVC over 3G UMTS Mobile Video Services

Jose Oscar Fajardo, Ianire Taboada, Fidel Liberal, and Armando Ferro

University of the Basque Country, Spain
joseoscar.fajardo@ehu.es
http://det.bi.ehu.es/NQAS

Abstract. This paper deals with the analysis of user perceived visual quality for mobile multimedia services. H.264/AVC is selected for low resolution video encoding, and 3G UMTS is considered for mobile data services. From subjective tests results, the combined impact of different service– and network–level parameters is inferred. As a result, different cross–layer adaptation alternatives are proposed to maximize the perceived quality level under different service conditions.

Keywords: Mobile multimedia services, H.264/AVC, 3G UMTS, adaptation.

1 Introduction

Multimedia applications have become increasingly popular over Internet. Furthermore, the wide–spreading of enhanced mobile Internet access and the continuous evolution of multimedia encoding techniques allow provisioning video services over mobile data connections at acceptable quality levels. For instance, the mobile version of the YouTube video sharing platform currently offers H.264/AVC–encoded video clips, which can be accessed from a mobile handset via RTSP with a standard video client. Typically, two versions of the video clips are available. On one hand, the normal version is based on the low spatial resolution (SR) of QCIF (176x144) and low encoding bitrate (about 80kbps). On the other one, the High Quality (HQ) versions offer a higher SR at QVGA –or square pixel SIF– (320x240) at higher encoding bitrates (about 250kbps).

The choice of the most suitable version depends on different parameters. The screen resolution of the mobile device imposes a first requirement. Nowadays, typical screen resolutions are QCIF, QVGA and VGA. As well, the performance variability associated to mobile data services must be considered. Taking into account a typical 3G Universal Mobile Telecommunications System (UMTS) service, the 384kbps bearer supports the requirements of HQ versions under perfect reception conditions. However, the variable radio conditions may introduce degradations in the transmission, and the normal version could be preferred.

As widely studied, an adaptive approach could provide the best quality level all over the service time by introducing real–time modifications in the service

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provision configuration. This paper deals with this topic, focusing on the provision of H.264/AVC–based video services over 3G UMTS data connections. Specifically, the work presented here tries to offer a consolidated performance study by taking into account the combined effects of the specific characteristics of the UMTS Terrestrial Radio Access Network (UTRAN) on one hand, and the specific characteristics of the H.264 encoding on the other one. Additionally, both service– and network–level adaptations are proposed in a cross–layer approach. In order to perform the most suitable adaptation actions, the decision making process shall be driven by the expected visual quality level as perceived by end users. Extensive subjective tests have been performed in order to model the combined impact of the service and network conditions into the visual quality.

1.1 Background

The analysis of user perceived visual quality has been subject of many studies in recent years. With regard to H.264/AVC at mobile resolutions, several studies present their subjective tests results for service contexts similar to the considered in this paper.

From the subjective tests results presented in [1], the H.264/AVC codec can be assumed as the best performing codec for QCIF mobile video services. As well, the most suitable audio–video (A/V) bitrate ratio is inferred as a function of the content type (CT). In [2] authors study the combined effects of the source bitrate (SBR) and frame rate (FR) for mobile resolutions. The main outcome is a regression–based expression which relates the Mean Opinion Score (MOS) to the SBR and FR values for different CT. The FR is considered in the range of 5 fps to 15 fps, while the target SBR varies from 24kbps to 105kbps. In this case, all the subjective test sequences are presented at QCIF resolution screen, which justifies the low values considered for SBR. This range of SBR values is considered insufficient for the aims of this paper, where higher SR values are considered. As well, in these studies only the encoding parameters are considered, assuming ideal transmission conditions.

Concerning higher SR, e.g. results in [3] present quality evaluations of CIF (352x288) video sequences in terms of blocking, blurring and flickering artifacts. The SBR is considered from 100kbps to 300kbps for this SR at 25fps. However, only the encoding effects are considered for the quality analysis as well.

Both H.264/AVC CIF video sequences and transmission effects are considered in the analyses of perceived video quality presented in [4] and [5]. In both cases, a 2–state Markov model is used to implement the bursty packet losses. However, in both cases the loss model is implemented at IP level. In our case, the bursty error pattern is implemented at UMTS Radio Link Control (RLC) level following the results shown in [6], where the error pattern is obtained from live UMTS network traces. This feature entails a better emulation of the combined effects of the service–level settings and the experienced UMTS performance conditions.

As a result, although all the reviewed studies are close to the case study, none of them covers all the objectives proposed in this paper and hence new subjective tests have been performed.

1.2 Scope and Objectives

The main objective of the study is to in–depth study the combined impact of different service– and network–level parameters into the experienced visual quality from a consolidated standpoint, in order to analyze the most suitable cross–layer adaptations that maximize the Quality of Experience (QoE). In this sense, the main contributions of this paper are twofold:

– A thorough analysis of the visual quality which could be expected in a mobile multimedia service, as currently being provided in real–world services.
– A dynamic cross–layer adaptation mechanism based on three configurable parameters, aimed at maximizing the QoE under variable UMTS service conditions.

One of the main novelties of the paper is the mobile multimedia service awareness. All the subjective tests have been performed resembling actual service conditions, including mobile–oriented media encoding and presentation to end users. As well, the used UMTS reception patterns are based on real–world measurements under different mobility scenarios.

The remainder of this paper is structured as follows. Section 2 presents the methodology followed for performing the subjective tests. Section 3 focuses on the analysis of perceived visual quality, in function of the encoding settings. From subjective tests results, the evolution of expected MOS with the SBR is inferred for each CT and SR. This way, the most suitable SR can be identified for the achievable SBR and per CT. Likewise, Section 4 focuses on the analysis of perceived visual quality in function of the UMTS performance. From subjective tests results, the evolution of expected MOS with the experienced UMTS conditions is inferred for each CT. This way, the most suitable SBR can be identified for the experienced Block Error Rate (BLER) and per CT. Section 5 states the considered adaptation capabilities and discusses the expected improvement in terms of QoE. Based on the subjective testing results, a cross–layer adaptation mechanism for mobile video streaming services is proposed and evaluated. Finally, Section 6 gathers the main conclusions to this paper.

2 Subjective Testing Methodology

The experimental design for the subjective video tests is mainly based on ITU recommendations and tutorials [7] [8] [9]. Different aspects are taken into account for planning the subjective tests for this kind of multimedia applications.

Concerning the viewing conditions, video sequences are presented to end users resembling a mobile UMTS service in order to enhance the accuracy of results [10]. All video sequences are displayed in a mobile handset and users are asked to hold it in their hands. The device used in the tests is a Nokia N95-8Gb, which provides a 320x240 screen resolution. The tests are carried out with RealPlayer for s60, which uses image re–scaling for presenting QCIF sequences at full screen.

The video sequences are a priori generated including both encoding and transmission effects, and they are stored in the mobile device for its presentation to subjects. So, an appropriate device and displaying format is used to achieve the proposed objectives in a fixed environment conditions for all the subjects. In order to capture the combined effects of the specific encoding and transmission techniques, long duration video sequences (about 2 minutes) have been used instead of the typical short (about 10s) reference video sequences.

Taking as reference the proposed test structure in [7] [8] and [9], before starting with test sessions, written instructions were shown to subjects and a training phase was done in which some videos are presented and evaluated, without taking into account these results. Then this is followed by several test sessions. In each test session different types of test scenes are shown. These are presented in random order and some implicit replications are included to check coherence [7]. Due to fatigue issues, break periods between sessions are introduced [9]. For carrying out the different experiments proposed in this study, each subject participates in the experiments for three different days.

In order to reproduce viewing conditions that are as close as possible to real–world contexts, Single Stimulus (SS) tests are used and the audio track is also included in the multimedia stream. The evaluations are based on Absolute Category Rating (ACR). Thus, after each test sequence presentation the subjects are asked to evaluate the quality of the presented sequence in the MOS scale of 1 to 5.

3 Service–Level Parameters

Three different CT have been considered: low–motion (LM), medium–motion (MM), and high–motion (HM) video sequences. As seen in [11], there are different alternative approaches for content classification based on the spatial and temporal activity of the whole video sequences. Besides, other studies (e.g. [12]) propose the use of a single content motion estimation metric in a dynamic way all over the video sequence. In this paper, the content categorization has been performed following the parameters proposed in [13], which associates an scene complexity (C) and level of motion (M) value to each video sequence based on the average bits per frame and the average quantization parameter (QP) for I and P frames respectively. These metrics allow implementing an easy estimation of the content complexity directly from the results of the encoding process. All the video sequences have been encoded with the H.264/AVC Joint Model Reference Software. The considered content and associated complexity metrics are described as follows:

- LM sequence is made up of news video clip with two people, including change of planes and a commercial in middle of the sequence (C=0.62; M=0.96).
- MM sequence is a typical TV series scene, featuring different people and including change of planes (C=0.49; M=0.42).
- HM sequence is taken from a basketball top 10 best plays video sequence, with changes of planes from field to face planes (C=0.46; M=0.28).

Instead of analyzing the visual quality as a function of the combined setting of FR and SBR, in this study only the SBR is modified. The FR values are set up

Table 1. Encoding settings for subjective tests

CT	SBR (kbps)	SR	FR (fps)
LM	{80, 130, 200}	320x240	10
	{48, 88, 128}	176x144	10
MM	{80, 130, 200}	320x240	12.5
	{48, 88, 128}	176x144	12.5
HM	{80, 200, 256}	320x240	15
	{48, 88, 128}	176x144	15

in function of the content dynamics: 10, 12.5 and 15 fps are established for LM, MM and HM respectively. Table 1 summarizes the considered values.

The H.264/AVC encoder is set up to its Baseline Profile at level 1.2. The frame structure is IPPP, with a Group of Pictures (GOP) size of 10 seconds. Thus, each 10 seconds the video sequence is refreshed with a new I frame.

3.1 Encoding Quality

First, subjective tests were performed for evaluating the impact of SBR into the encoding quality of QVGA sequences. A total of 20 people evaluated each sequence, for a total of 180 tests. The obtained results are presented in Fig. 1, which gathers the box plots of the subjective testing results for the whole set of considered CT–SR conditions. For each combination of CT and SBR considered, the median, Q1 and Q3 percentiles and minimum/maximum values are illustrated. As well, those values which are considered outliers in the data sample are individually plotted. Outlier values are determined by the Chauvenet's Criterion and they are not taken into account in the computation of the MOS. Table 2 shows the average quality values derived from the subjetive tests for QVGA resolutions.

Table 2. Subjective tests results for QVGA

SBR (kbps)	LM	MM	HM
80	3.49	2.90	1.98
130	4.26	3.92	–
200	4.53	4.49	3.73
256	–	–	4.26

Similarly, new tests were performed for the QCIF versions of the same videos. In order to resemble actual service conditions, QCIF video sequences are presented at full screen in the mobile handset with RealPlayer, so image scaling is required. A total of 20 people evaluated each sequence, for a total of 180 tests. In this case only the averaged MOS values are provided in Table 3.

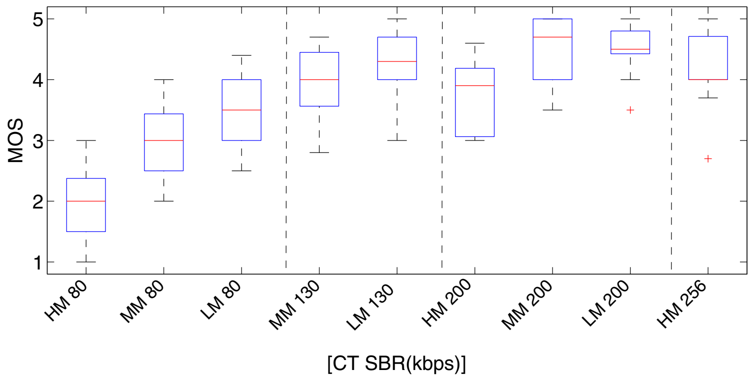

Fig. 1. Boxplot of subjective testing results for encoding of QVGA sequences

Table 3. Subjective tests results for QCIF

SBR (kbps)	LM	MM	HM
48	3.49	2.75	1.83
88	3.52	3.46	2.65
128	3.66	3.60	2.91

The QCIF versions, being half the size than the QVGA sequences, require less SBR to achieve an acceptable visual quality. However, the increase of SBR does not entail a proportional increase in the perceived quality for different SR values. As described in [5], the video encoding process may reach the visual quality threshold and above this threshold a higher SBR is not captured by the human visual system.

3.2 Impact on Service–Level Adaptation

In order to evaluate the evolution of both alternatives, we applied fitting techniques to the subjective results and obtained an approximation of the relationship between MOS and SBR values for both SR. The fitting function is given in equation 1 as proposed in [5].

$$MOS = a \cdot log(SBR) + b \tag{1}$$

Parameters a and b are related to the activity level of the content and spatial resolution, and the obtained values are illustrated in Table 4.

By using these results, Fig. 2 presents the expected evolution of the subjective visual quality in terms of MOS for each pair of considered CT–SR values. For each CT, the two resulting curves cross at a specific point (SBR_{th}) and two

Table 4. Experimental coefficients for the fitting function

	LM QVGA	MM QVGA	HM QVGA	LM QCIF	MM QCIF	HM QCIF
a	1.141	1.739	2.274	0.159	0.608	1.124
b	-1.442	-4.665	-7.954	2.858	0.556	-2.48

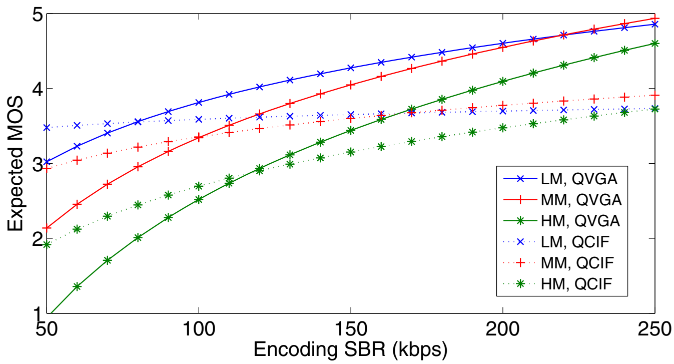

Fig. 2. Evolution of expected MOS vs. SBR per CT and SR

differentiated regions are identified. For SBR values lower than SBR_{th}, it is preferable to switch to a lower SR in order to control the impact of the limited SBR. The SBR_{th} value is higher for more dynamic sequences. For the three CT considered in this study, we find that this threshold is around 80, 100 and 115 kbps for LM, MM and HM respectively.

4 UMTS Access Network

The scope of this paper regards to the provision of mobile video streaming services over a typical wide–area 3G UMTS data service, as defined in 3GPP TR 25.993 [14] for the $Interactive or Background/UL : 64 DL : 384 kbps/PS RAB$. This kind of bearer service provides a maximum downlink bitrate (DLBR) of 384kbps. A detailed description of the considered service provision and the impact of the UTRAN is given in [15].

From the total bitrate, the final amount available for the video encoding process is reduced by several factors. First of all, the RTP/UDP/IP packetization introduces an overhead in the data transmission. Second, we must consider the effect of the audio stream within the multimedia transmission. The analysis of the audio quality and the integral quality (as shown e.g. in [16]) is out of the scope of this paper. Yet, the impact of its transmission is simulated by adding a 64 kbps stream to the considered video stream. Finally, part of the DLBR is used by the RLC AM functions for the local recovery of lost MAC PDUs. In this sense, the performance of the video streaming service highly depends on the radio error pattern.

As cited in Sect. 1.1, one of the novelties of this paper is that the UMTS error model is implemented at RLC level from real–world measurement results, instead of using a typical 2–state Markov model for simulating the IP–level loss events. For the simulation of different network conditions, the implemented error model is a 2–state Markov model with variable Block Error Rate (BLER) values.

Two characteristics are adopted from the results presented in [6]:

– For mobile users, the radio errors can be grouped at Transmission Time Interval (TTI) level.
– The Mean Burst Length (MBL) of erroneous TTIs can be approximated to 1.75.

The error model, as well as the simulation methodology, is further detailed in [17]. The RLC–level error model, in combination with the application–level settings, determines the performance of the service. The RLC errors may derive to additional delays if the RLC is able to recover the lost PDU, or to video frame losses otherwise.

Taking into account the relevance of the different frame types, a content–aware scheduling is implemented in a similar way to the concepts proposed in [18] for 3G UMTS and in [19] for HSDPA. In this case, the priority of different RLC retransmissions is modified in order to implement an enhanced protection for I frames. This way, we prevent severe degradations in the initial picture of each GOP and its propagation all over the 10 seconds period.

4.1 3G UMTS Transmission Quality

Considering the mentioned characteristics for 3G UMTS mobile multimedia services, different combinations of service and network conditions are simulated. All the simulations are run with OPNET Modeler, where both the specific UMTS error pattern and a H.264/AVC RTP trace injector have been implemented. QVGA video traces corresponding to the three CT have been used in the simulations with several SBR values. 80, 130 and 200 kbps have been considered for LM and MM video sequences, while an additional 256 kbps version has been used for HM traces. All the traces have been transmitted several times from a video server to the mobile endpoint, traversing the UMTS network segment. The downlink BLER value in the radio part is set up from 1% to 30% at 5% steps. At 30% of BLER, all the sequences experience high degradations except for the LM 80kbps versions.

From the whole set of results obtained, a mapping between different BLER values and experienced IP Loss Ratio (IPLR) patterns is established. For those points with negligible IPLR values (under 0.1%), the service performance is considered accurate. Similarly, high IPLR values (over 5%) indicate unaffordable service conditions.

The rest of intermediate points are considered for subjective evaluation of the visual quality perceived by users. Table 5 presents all the service– and network–level conditions that have been included in this set of subjective tests. The application–level performance (in terms of IPLR) is not only determined by the experienced BLER values, but also by the different traffic patterns associated to the different CT. Thus, different conditions require subjective evaluation in function of the CT. For the aims of this study, a total of 114 subjective tests were performed by 20 people.

Table 5. SBR and BLER settings for subjective tests

CT	SBR (kbps)	BLER(%)
LM	130	15, 20, 25
	200	5, 10
MM	130	20, 25
	200	5, 10
HM	256	5

Fig. 3 illustrates the results obtained from subjective tests for the considered encoding/transmission conditions. As can be observed, especially two conditions (namely LM–130–20 and MM–200–10) show a high variability in the quality scores provided by users. In those cases, the associated MOS are 2.15 and 2.58 respectively.

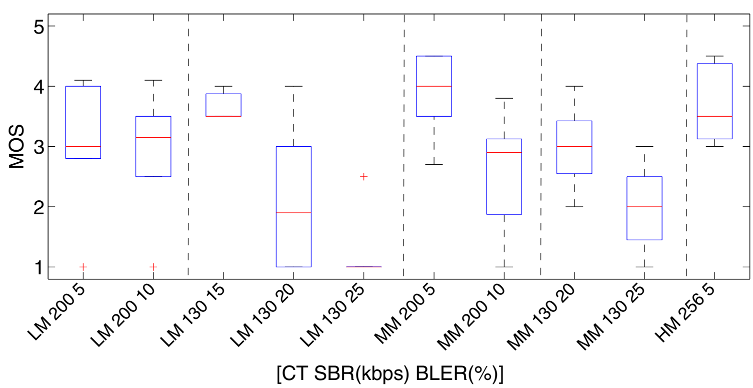

Fig. 3. Boxplot of subjective testing results for UMTS transmission of QVGA sequences

4.2 Impact on Cross–Layer Service Adaptation

The extensive results obtained both from the analysis of simulation results and from subjective tests allow us depicting a mapping between the application and transmission conditions to the expected video quality in terms of MOS, as shown in Fig. 4 for each considered CT.

From the behavior illustrated in Fig. 4, each combination of CT, SBR and BLER determines the expected visual quality value. Thus, for a specific BLER value, the video streaming session can be set up to the new SBR value that maximizes the expected MOS. For the aims of this paper, this adaptation is considered as a standalone decision making process.

The BLER value is not modified (e.g. by modifying the power control functions of the link layer) so the impact of the adaptation of a video stream on the performance experienced by other users in the same cell is limited in this case.

If power or rate control mechanisms are considered in multi–user environments, where several users are contending for the access to limited cell resources at the same time, the optimization problem can be studied as shown in [20].

Another alternative in the standalone management of mobile services is the capability of modifying the Radio Bearer settings in function of the experienced conditions. If for the experienced BLER condition none of the highest considered

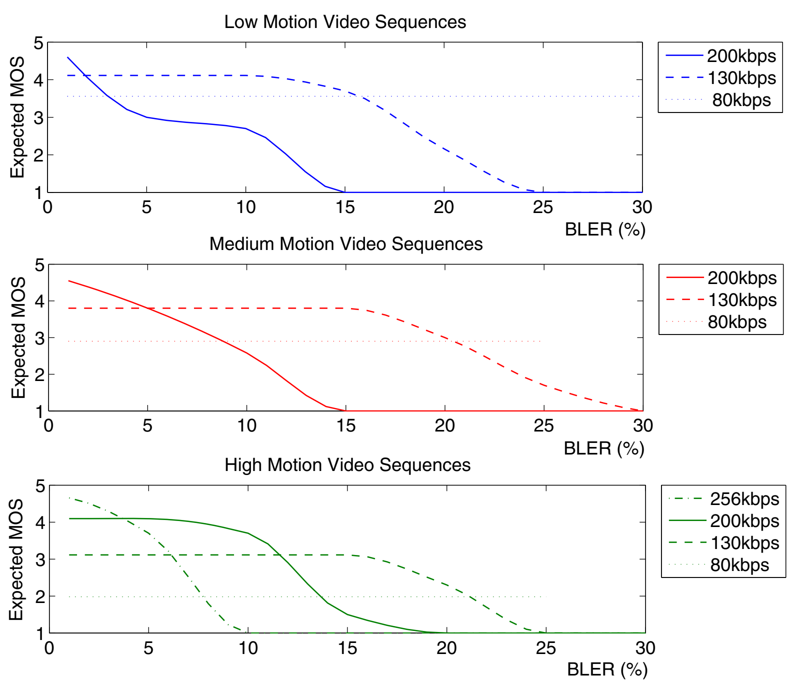

Fig. 4. Evolution of expected MOS vs. BLER per CT and SBR for QVGA sequences

SBR values is suitable, the UMTS Radio Bearer can be switched to a DLBR value of 128 kbps, which exhibits a better resilience to noise and interference at the same transmission power levels. Thus, low BLER values can be expected in order to guarantee no further impairments than the encoding process itself.

At the same time, the multimedia streams are switched to a lower SBR in order to cope with the new DLBR requirements. As a result, this approach entails a combined encoding/network service adaptation. As in the previous case, the impact on other users is limited and each user can be adapted by itself.

5 Evaluation of Cross–Layer Adaptations

Based on the results obtained from the subjective tests, different adaptation approaches can be evaluated. Four alternative approaches are considered, each option including a new adaptation capability from zero to three configurable parameters.

- *No Adaptation (NA).* In this case, no adaptations actions are considered. Thus, the achieved MOS values are those corresponding to the initial service conditions. In order to offer accurate quality levels, for LM and MM sequences the initial SBR is set up to 200kbps, while HM sequences are configured to 256kps.
- *Network–Aware Bitrate Adaptation (NABA).* This alternative considers the adaptation of SBR to the value that maximizes the expected MOS for the specific CT and experienced BLER, driven by the estimation curves shown in Fig. 4. For the purposes of this paper, the allowed SBR values are 256, 200, 130 and 80 kbps.
- *Network–Aware Bitrate and Spatial Adaptation (NABSA).* This approach takes into account the two configurable service–level parameters considered in this paper: SBR and SR. Thus, based on the resulting SBR adaptation, the SR is also switched from QVGA to QCIF if the optimal SBR is lower than the SBR_{th} for the specific CT as illustrated in Sect. 3.2.
- *Network–Aware Cross–Layer Adaptation (NACLA).* In this case, a cross–layer adaptation is adopted by taking into account the three parameters considered. Besides the application–level adaptation (combined SBR/SR), the DLBR can be decreased to overcome severe degradation conditions in the UMTS data connection.

Fig. 5 shows the obtained results for each dynamic adaptation approach, taking into account the different CT considered.

For LM sequences, only two curves are differentiated. If no dynamic adaptation is applied, the mobile video service gets completely degraded around the 15% of BLER. However, the service can be kept at suitable quality levels (MOS=3.5)

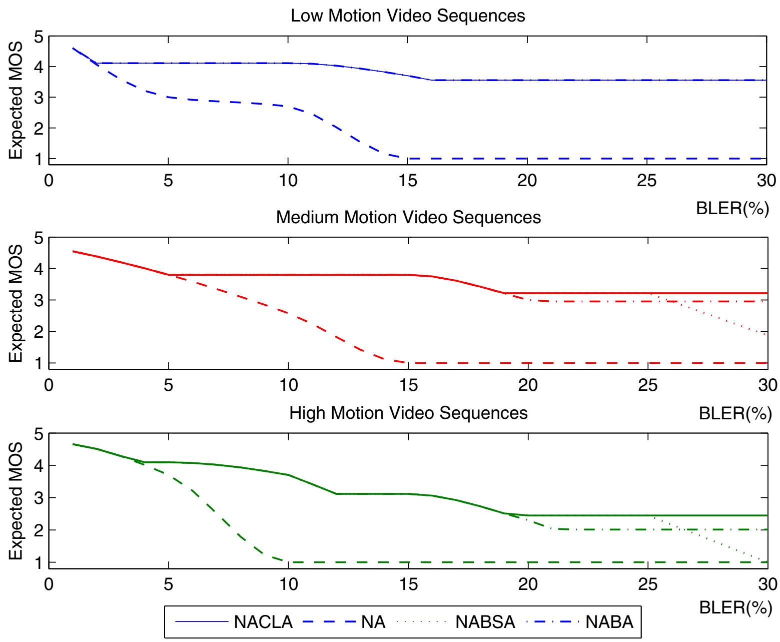

Fig. 5. Quality achieved by the different adaptation approaches

just with bitrate adaptation under the analysed UMTS conditions. The LM sequences exhibit no degradations at BLER=30%, and both SR versions provide similar quality levels at SBR=80kbps. Hence, the three dynamic adaptation approaches offer analogous behaviours at the whole range of the BLER conditions studied. Thus, just SBR adaptation provides the maximum achievable quality under different conditions in this case.

As can be observed, this is not case for MM and HM sequences. On one hand, the SBR_{th} is located above 80kbps in both cases, and thus the SR should be switched to QCIF when SBR is set up to 80kbps. On the other hand, the QCIF versions exhibit frame losses when the experienced BLER is above 25%. As a result, the three dynamic adaptation approaches provide different quality levels under severe UMTS degradations and different type of adaptations are required in order to maximize the QoE.

From the analysis of results, a dynamic network–aware cross–layer adaptation mechanism can be proposed, as illustrated in Fig. 6. Following the depicted logic, a mobile endpoint could be capable of launching the required adaptation procedures to keep the mobile video service in the maximum achievable quality level along the service time.

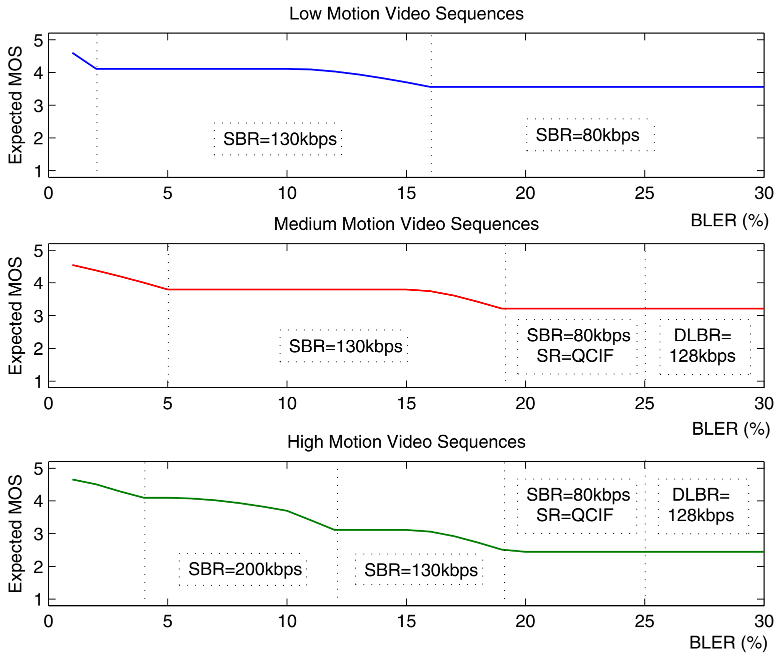

Fig. 6. Dynamic configuration and maximum achievable quality

6 Conclusions

This paper deals with possible dynamic adaptations for H.264/AVC based video services over 3G UMTS mobile connections. In order to get an optimal configuration, different cross–layer adaptations are proposed and evaluated. Thus, both service– and network–level adaptations are considered to cooperate in a coordinated way in order to maximize the QoE.

Since the proposed adaptations are driven by the expected QoE, specific subjective tests have been performed to cope with the specific service context. Thus, both specific H.264/AVC parameters and specific error models for commercial UMTS networks have been used. The outcomes of the subjective testing phase are later considered as inputs for the dynamic service adaptation logic.

Different adaptation approaches have been evaluated, considering different number of variable parameters. As a main result of this paper, we can state the enhancements of the three–parameter adaptation approach, based on the combination of encoding bitrate, spatial resolution and UMTS bearer bitrate. As described in Section 5, the considered adaptations do not have an impact on other users, so it can be implemented in a per–user basis.

In order to implement the adaptation logic at the mobile endpoint, the mobile device requires access to low–level parameters. Currently, several Android–based commercial mobile devices are capable of providing BLER statistics in real–time. As a work in progress, we have developed the software to capture these statistics from the chipset in order to make them available for the applications.

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