Online QoE Computation for Efficient Video Delivery over Cellular Networks

Telemaco Melia, Alcatel-Lucent laboratories, Villarceaux, France
Daniele Munaretto, Leonardo Badia, Michele Zorzi, Department of Information Engineering, University of Padova, Padova, Italy; Consorzio Ferrara Ricerche (CFR), Ferrara, Italy
telemaco.melia@alcaltel-lucent.com, {munaretto, badia, zorzi}@dei.unipd.it

1. Introduction

The rise of mobile video streaming has attained unpredictable scores in the past few years. The availability of smartphones combined with broadband wireless access technologies provides to mobile users great always-on experience making content consumption as easy as sending an SMS. When a user either points her browser to a video sharing website, such as YouTube, or opens an HTTP adaptive streaming session, she just enjoys the video stream while in the background optimized procedures select the optimal location (cache, storage) from where to download the content.

Commonly deployed solutions such as GeoDNS allow a requesting client to resolve a specific fully qualified domain name and to be redirected to a suitable cache depending on its geographical location. While these approaches work to a great extent over the public Internet, they suffer from shortcomings when deployed in a mobile environment, since the mobile network infrastructure is exploited as a pure Internet pipe. While this is obviously an advantage for over-the-top players such as YouTube, Google, and Facebook, it becomes a great challenge for mobile service providers. The disconnect between Average Revenue Per Unit (ARPU) and cost per bit requires the development of new solutions to solve network capacity issues while addressing new business models. Mobile service providers need in fact to enter the video distribution value chain to better satisfy their customers and potentially generate new sources of revenue.

The integration of Content Delivery Network (CDN) technology in the mobile service provider network is a promising path. Making online content directly available from the operator network opens the door to a whole new range of optimizations taking into account traditional network metrics [1] as well as wireless specific metrics, since the last radio hop represents the real bottleneck in many broadband networks. The optimization of these parameters is not trivial. The task of defining a combination through a proper weighting and fine tuning may be formidably complex, thus limiting a viable optimization only to locally efficient operating points, solutions only valid for a given time interval, and heuristic approaches. Thus, the evaluation and optimization of the perceived Quality of Experience (QoE) is far from being a solved problem. In the literature, offline solutions exist but they do not take into account the dynamic nature of wireless channels. In our work we demonstrate the efficiency of online tools with respect to offline tools and we highlight the difficult points that need to be addressed.

2. Offline vs. online QoE computation

QoE is typically measured offline in subjective experiments, such as the Mean Opinion Score (MOS), which is the average over all viewers' rating for a given video. Subjective experiments have the drawback of requiring a large set of viewers in a reasonably short amount of time. Hence, this is not appealing for real-time monitoring or streaming applications.

In the last decade objective and subjective quality metrics have been designed to characterize and predict the viewer MOS. Starting from the offline objective metrics, the Mean Squared Error (MSE) and Peak Signal-to-Noise Ratio (PSNR) are objective measurements of the video quality. They are used in Quality of Service (QoS) based video assessment systems. The main advantage of these metrics is that they are computationally simple and straightforward, while the drawback is that comparing PSNR values with the perceived video quality at the user side, significant discrepancies may appear due to their distortion and content-agnostic nature.

Better visual quality metrics have been designed to take into account the impact of distortions and of the video content on the QoE. The Structural SIMilarity (SSIM) [2] index, for instance, and its adaptation for video, VSSIM [3], compute a distortion map from measurements performed on small patches of a video frame. Offline full-reference metrics, computationally light and simple to implement, such as MSE and PSNR, perform a comparison frame-by-frame between the source and the received videos.

Opposite to the full-reference metrics, the no-reference metrics analyze only the received videos, thus they make it possible to design online methods for the measurement of the QoE. As a direct consequence of their nature, the no-reference metrics are more flexible than the full-reference metrics, but they work based on theoretic assumptions about video content and distortions. The no-reference metrics are thus appealing for real-time services, while the full-reference metrics are more suitable for offline applications, but they require more computational efforts.

Finally, we remark that most approaches for evaluating video quality are not suitable for wireless access networks, since they mostly focus on instantaneous evaluations of stationary quality values, without taking any memory effect into account. In reality, not only is the radio channel highly variable over time, but also video traffic is particularly sensitive to error correlation, which is fairly frequent in wireless scenarios. As a result, error propagation phenomena may occur, in which case the perceived video QoE rapidly drops [4]. An analysis of how to counteract it by properly designing error-control methodologies is far from being trivial [5]. In this paper, we simplify this problem by assuming the availability of sufficiently frequent updates on the perceived QoE. Our research focuses on the design of a method for online QoE estimation based on a no-reference approach. We aim at taking into account the features of the radio access channels, with particular emphasis on their time-varying and unreliable character.

Our key idea is that in a mobile network a video application can be served through different paths, resulting in different QoE, measured at the end user, and fed back to the network, possibly with tight granularity so as to track user mobility and channel variations. Thus, the mobile operator is in charge of guiding the service to keep a target QoE and to optimize the network resource usage.

3. A novel cross-layer approach at the terminal side

In this work we propose a new concept of QoE online computation where we take into account metrics impacting the quality perceived by the user from the Core Network (CN), i.e., involving CDN-related metrics, and from the Radio Access Network (RAN), i.e., related to wireless channel metrics. The combination of these two sets of metrics opens the door to a promising research avenue taking into account issues related to the whole video delivery chain. Moreover, we intend to develop, based on these metrics, an online no-reference QoE computation method suitable for mobile devices. The key idea is to combine metrics that specify a typical CDN environment [1] with wireless metrics. The mobile operator has the unique possibility of combining both worlds and of proposing fast adaptive algorithms to optimize the perceived QoE. Figure 1 depicts a simplified vision of the Evolved Packet Core (EPC) enhanced for optimal CDN integration [4].

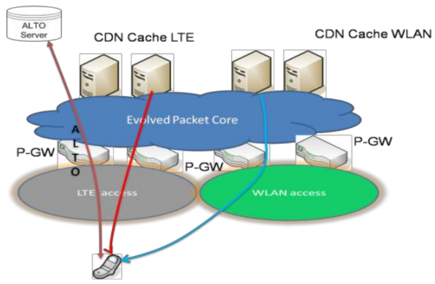

Figure 1. Mobile Network Architecture.

CDN caches are integrated on top of the existing Packet Data Network (PDN) gateways (P-GWs, giving Internet access to mobile devices) and take into account the diversity of both cellular and Wireless Local Area Network (WLAN) access. Latest extensions of the 3GPP specifications propose the deployment of several P-GWs with both local and global scope. This way, the same content can be potentially downloaded from several sources, each having different properties with respect to the underlying wireless technology and round trip time delay. To this end, the Application Layer Transport Optimization framework (ALTO) [5] proposes extensions accounting for the specific metrics of a mobile wireless deployment. It should be further noted that at the time of this writing the standardization process has just begun, leaving to researchers the great opportunity to impact the next release of the specifications.

The foreseen metrics in our approach are as follows. CDN-related metrics consider the distance of a specific End Point (EP), i.e., CDN cache, expressed in number of hops between the mobile device and the EP, and the computational load of an EP, expressed in terms of memory occupancy. Wireless metrics consider the Signal-to-Noise

Ratio (SNR) and the channel rate of both cellular and WLAN access, combined to allow sequential or simultaneous use of both technologies (i.e., accounting for multi-homed mobile devices).

Regarding the wireless side of the online QoE computation approach, we give an example of scenario to best highlight our innovative step. Consider a mobile user walking in an Long Term Evolution (LTE) micro-cell, with 20 MHz of bandwidth, and an area coverage of up to 2 km. We further deploy 3 WiFi 802.11n spots, with bandwidth of 20 MHz, at regular intervals of 0.5 km from the LTE base station. By running in Matlab two own-developed LTE and WiFi modules, we obtain values of average SNR with respect to the distance from the LTE base station as plotted in Fig. 2. It is evident that, once the user is in range of a WiFi hot spot (blue, red and black peaks in Fig. 2), the exploitation of this additional access technique, which should happen simultaneously on both LTE and WiFi channels, may be beneficial to both the user and the network operator. For the latter, it will result in additional available capacity to redistribute to the users that are not under coverage of any WiFi hotspot. For the former, video quality can be highly increased. Finally, assuming the delivery of a scalable video, i.e., encoded with the video compression standard H.264-SVC (Scalable Video Coding) [6], we might choose to deliver the base video quality through the LTE channel, which is always available, leaving the enhancement video layers to the WiFi channel, when available.

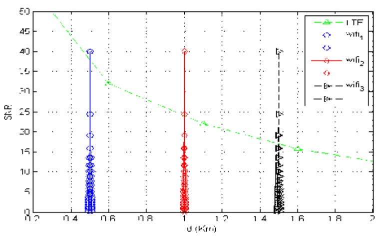

Figure 2. Wireless Scenario: single user' SNR vs. distance.

4. Cost for network operators vs. user's QoE

In the previous section we presented a possible set of metrics that we intend to consider in our online QoE computation approach. Our idea is to build vectors reflecting each possible path of the whole video delivery chain, from a video source (cache) to the mobile user (terminal).

The goal of our work is to find the optimal vector of values for both CDN and wireless related metrics. Optimality here has a different meaning whether we consider the network operator's or the user's point of view. We aim at optimizing the set of vectors based on two different criteria reflecting the requirements of service providers and users. The common set of solutions is the optimal set taking into account both network operator and user's sides. It is likely that the two solution spaces do not coincide, since the cheapest solution for a network operator in terms of resource usage unlikely gives the best QoE to the end user. Enhancing the perceived quality of a video comes at a cost, which usually results in higher bit rates to be provided by the network operator.

We foresee the design of a framework, to be implemented on the mobile terminal, which runs a computationally light optimization algorithm in real-time to best select the path for the video delivery, ensuring a target user's QoE level under the constraints of the available network resources, i.e., network operator's costs.

5. Conclusions

In this work we propose a new challenge for the online computation of the video quality perceived by a mobile user. The design of a heuristic algorithm for the optimization of the network and quality metrics that affect the QoE of a user at the mobile terminal is currently work in progress.

6. Acknowledgement

This work is supported by the EU research project MEDIEVAL (MultimEDia transport for mobIlE Video AppLications), a focused research project (STREP) of the 7th Framework Programme of the European Commission.

References

[1] Akamai Media Analytics, Akamai Technologies Inc., White Paper, 2009.

[2] Z. Wang, A. Bovik, H. Sheikh and E. Simoncelli, "Image quality assessment: from error visibility to structural similarity", *IEEE Transactions on Image Processing*, vol. 13, no. 4, pp. 600-612, Apr. 2004.

[3] Z. Wang, L. Lu and A. C. Bovik, "Video quality assessment based on structural distortion measurement", *Signal Processing: Image Communication*, vol. 19, no. 2, pp. 121-132, 2004.

[4] K. Stuhlmüller, N. Färber, M. Link and B. Girod, "Analysis of video transmission over lossy channels," *IEEE J. Selected Areas of Communications*, vol. 18, no. 6, pp. 1012–1030, Jun. 2000.

[5] L. Badia, N. Baldo, M. Levorato and M. Zorzi, "A Markov framework for error control techniques Based on selective retransmission in video transmission over wireless", *IEEE J. Selected Areas of Communications*, vol. 28, no. 3, pp. 488-500, April 2010.

[6] "3GPP TS 23.401", 3GPP Specification Detail, available at http://www.3gpp.org
[7] "ALTO Status Pages", [Online] available at http://tools.ietf.org/wg/alto/
[8] H. Schwarz, D. Marpe and T. Wiegand, "Overview of the scalable video coding extension of H.264/AVC", *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 17, no. 9, pp. 1103-1120, 2003.

Telemaco Melia received his Informatics Engineering degree in 2002 from the Polytechnic of Turin, Italy and his PhD in Mobile Communications from University of Göttingen in April 2007. From June 2002 to December 2007 he worked at NEC Europe Ltd. in Heidelberg, Germany in the Mobile Internet Group. He worked on IPv6 based Mobile Communication focusing on IP mobility support across heterogeneous networks and resource optimization control. In September 2008 he joined Alcatel Lucent Bell Labs. He is currently working on inter-working architectures spanning 3GPP, Broadband forum and IETF standardization bodies. His main research interests include wireless networking and next generation networks. He authored more than 20 publications and he actively contributes to the IETF. He is project co-ordinator of the EU funded MEDIEVAL project (www.ict-medieval.eu).

Daniele Munaretto received the BS and MS degrees (with honors) in Telecommunication Engineering in 2004 and 2007, respectively, at the University of Padova, Italy. After an internship for his MS thesis at DOCOMO Euro-Labs, in Munich, Germany (2006–2007), he joined Euro-Labs from 2007 to 2010 as R&D Engineer in the Ubiquitous Networking Research Group. He is currently a first year Ph.D. student at the Department of Information Engineering at the University of Padova, under the supervision of Prof. M. Zorzi. His research interests mainly cover wireless networks, network coding, video streaming applications and P2P networks. He authored several scientific papers and EU patents.

Leonardo Badia received the Laurea Degree (with honors) in Electrical Engineering and the Ph.D. in Information Engineering from the University of Ferrara, Italy, in 2000 and 2004, respectively. During 2002 and 2003 he was on leave at the Radio System Technology Labs (now Wireless@KTH), Royal Institute of Technology of Stockholm, Sweden. After having been with the University di Ferrara and the IMT Advanced Studies Institute in Lucca, Italy, he joined in 2011 the University of Padova, where he is currently an Assistant Professor. His research interests include protocol design for wireless networks, transmission protocol modeling, optimization of radio communication, and applications of game theory to radio resource management. He authored about 100 scientific papers and serves on the Editorial Board of the Wiley Journal of Wireless Communications and Mobile Computing.

Michele Zorzi received his Laurea degree and Ph.D. in electrical engineering from the University of Padova, Italy, in 1990 and 1994, respectively. During academic year 1992/93, he was on leave at the University of California, San Diego (UCSD) attending graduate courses and doing research on multiple access in mobile radio networks. In 1993, he joined the faculty of the Dipartimento di Elettronica e Informazione, Politecnico di Milano, Italy. After spending three years with the Center for Wireless Communications at UCSD, in 1998 he joined the School of Engineering of the University of Ferrara, Italy, and in 2003 joined the Department of Information Engineering of the University of Padova, Italy, where he is currently a Professor. His present research interests include performance evaluation in mobile communications systems, random access in mobile radio networks, ad hoc and sensor networks, energy constrained communications protocols, cognitive networks, and underwater communications and networking. He was Editor-in-Chief of the IEEE Wireless Communications magazine from 2003 to 2005 and Editor-in-Chief of the IEEE Transactions on Communications from 2008 to 2011, and serves on the Editorial Board of the Wiley Journal of Wireless Communications and Mobile Computing. He was also guest editor for special issues in IEEE Personal Communications and IEEE Journal on Selected Areas in Communications. He served as a Member-at-Large of the Board of Governors of the IEEE Communications Society from 2009 to 2011. He is a Fellow of the IEEE.