Evaluation of the Quality of Experience for 3D Future Internet Multimedia

Ivett Kulik and Tuan Anh Trinh

Department of Telecommunications and Media Informatics, Faculty of Electrical Engineering and Informatics, Budapest University of Technology and Economics, Budapest, Hungary
kulik@tmit.bme.hu, trinh@tmit.bme.hu

Abstract: Provisioning 3D video stream-based services online in an acceptable quality, even in a wireless access environment, is a big challenge for Future Internet service providers. Characterizing the necessary Quality of Service requirements is hard, since only a few empirical results are known about the user perceived 3D quality. In this paper a statistical analysis of subjective perception of 3D stereoscopic video Quality of Experience (QoE) are investigated with respect to network level QoS. The network is configured to demonstrate a real environment; thus, GPON-based aggregation is used. Our results show characteristics of QoE-QoS relationship in the case of 3D video playback. We also tackle the challenge by carrying out GPON-based transport network with IEEE802.11n standard based WiFi access measurements focusing the QoE of 3D content. And according to our results we propose cubic fitting function for modeling QoE-QoS relationship in the case of throughput degradation.

Keywords: 3D stereoscopic video; Quality of Experience-QoE; Quality of Service-QoS; GPON-based network; WiFi network; Mean Opinion Score-MOS; subjective evaluation

1 Introduction

The Internet has approached an historic turning-point, when mobile platforms and applications are poised to replace the fixed-host/server model that has dominated since its inception. The existing Internet architecture has been designed for efficient communication but not for real-time data distribution. The exponential growth of smart mobile devices with Internet access, and the need of users to be “always connected” definitely indicate that the Internet has become the core mobile communication environment for business, entertainment, education, and for social and human interactions.

Over the past decades, new network architectures and protocols have been proposed that sketch the idea of the Future Internet. Paul et al. [1] presented a comprehensive survey on the networking research on network architecture for future networks and the next generation Internet. The articular network neutrality aspect, where users are able to access any web content and to use any applications according to their choice without restrictions or limitations, is becoming the biggest challenge for Internet Service Providers (FISP).

FISP has to prepare for the capability to support multiple types of terminals, hosts and nodes, protocols and applications. The major design goals of FISP networks are: *mobility* as the norm with dynamic host and network mobility at scale; *robustness* with respect to intrinsic properties of wireless medium; *trustworthiness* in the form of enhanced security and privacy for both mobile networks and wired infrastructure; and *usability* features, such as support for context-aware pervasive mobile services, evolvable network services, manageability and economic viability.

The Future 3D Media Internet has generated a significant amount of research work recently, which should be designed to overcome current limitations of network architecture, involving content and service mobility, new forms of 3D content provisioning, etc. [15] [3]. A seamless delivery of 3D video streams means that the provider needs to be able to observe and react quickly to Quality of Service (QoS) problems in transport network, and the importance of Quality of Experience (QoE) appears as well. QoE are customer-centric metrics, while QoS is network-centric. Human perception of video streams is best characterized in term of QoE, which looks at the streaming content from the standpoint of end users. Today, in the era of increasing fast resolution, mobile-phone owners commonly watch movie trailers or whole films on their small favorite devices, while customer satisfaction will remain dominant criteria for future applications. Consequently, appropriate QoS support at the service providers side and satisfactory level of 3D video QoE at the client side provided through the wireless access for mobile handhelds remains a big challenge for Future Internet researchers, as well. Investigation of QoE characteristics based on QoS degradation for 3D multimedia contents delivery is in focus recently. The assessment of QoE in multimedia services can be performed either by subjective or objective methodologies [2].

More research subjects have brought into focus the QoE and QoS [3] [12] or evaluation of stereoscopic images [4] [11] [6] [10], but more investigations are needed for appropriate QoE provisioning in wireless network based networks. The Gigabit Passive Optical Network (GPON) GPON transport based test-bed with wireless client access is an appropriate representation of an environment for measurements, and recent research works have appeared for the evaluation of QoE for 3D multimedia delivery by means of QoS in Future Internet wireless access scenarios.

This contribution is publishing a few results of subjective tests carried out by participants focusing on describing the relationship between QoE and QoS for 3D contents delivery in a real network environment. Obviously, network level QoS parameters such as throughput, delay, jitter and packet loss affect user level QoE parameters. First, we carried out experiments based on subjective testing of 3D video files, where 50 participants observed QoE changes due to the degradation of QoS parameters. The results of this experiment are published in [15]. We followed up on our experiments and this contribution shows the results of the QoE-QoS relationship investigation when one video file was observed in 3D and 2D types of visualization, as well. 40 users watched videos with QoS degradations, while jitter increased and throughput decreased. The second part of this paper describes a few results of an experiment where 36 participants assessed the quality of 3D video content when the network was a representative combination of GPON-based transport network and IEEE802.11n standard based WiFi access.

The paper is structured as follows. In Section 2 we explain the network environment. Section 3 describes the method of measurements. Section 4 discusses results in the case of a GPON environment. Section 5 shows a few results with a WiFi network, from the client side. Finally, this paper is concluded in Section 6.

2 The Network Environment

Based on the 3D multimedia transport requirements, the appropriate test network was planned and realized. Basically, the multimedia server is connected with a broadband and reliable connection, and 3D video contents were transferred through the network in unicast mode using TCP transport. Types of encoding and compression affect the demand of bandwidth in the case of multimedia content transport. The used average bandwidth can be between 10 Mbit/s and 20 Mbit/s via stream, or more, but in the case of higher motion level scenes, even 40 Mb/s throughput is needed. Videos were displayed by the Nvidia Vision Player v1.6.

The GPON-based transport network was efficient with 2.5 Gbit/s download speed and 1.5 Gbit/s upload speed [7] via broadband and responsible access to video server with 3D multimedia streams. The whole GPON-based network architecture with wireless sub-networks on the client side is shown in Figure 1.

The GPON-based transmission network consists of four components: Optical Line Terminal (OLT) on the provider side, Optical Network Terminal (ONT) on the customer side, optical cables for connecting, and passive splitters that can split optical signals in split ratios 1:2. The OLT and ONT devices are managed by the Siemens EM-PX manager client. The hardware configuration of the server and clients are shown in the Table 1.

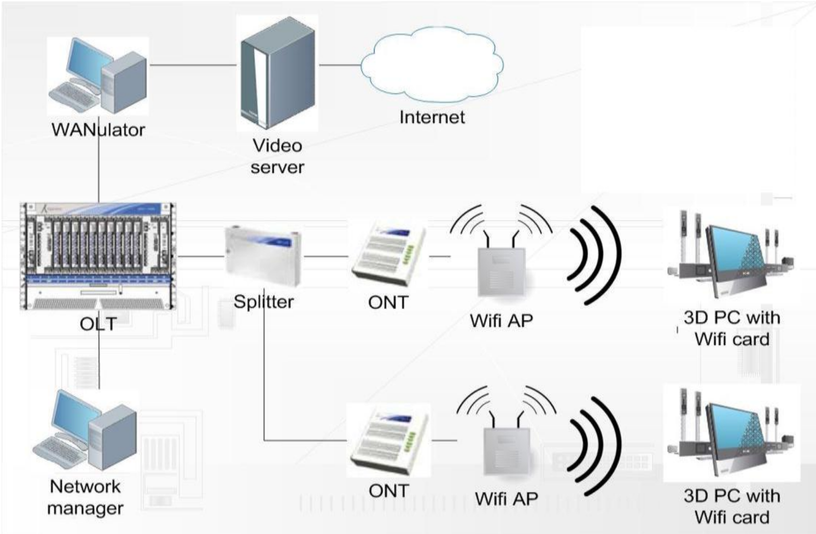

Figure 1
The GPON-based network with WiFi sub-networks for 3D video streams investigation

Table 1
Hardware configuration of the client and server

CLIENT	**Components**	**Notes**
Processor	Intel Core 2 Quad, Q8300, 2,5GHz	Needs: At least Intel Core 2 Duo, or AMD X2 Athlon
Video-card	NVIDIA GeForce GT 240	Needs: 8 series, 9 series or 200 series NVIDIA video-card
Memory	4GB RAM	
Spectacles	Nvidia 3D Vision	
SERVER	**Components**	
Motherboard	Asus P5B Deluxe	
Processor	Intel Core 2 Duo, 2,13GHz	
Memory	1 GB RAM	

The video server was responsible for the storage and sharing of the 3D and 2D video files, which was guaranteed by the VLC program. The WANulator software simulated different Internet conditions, such as delay, jitter or packet loss, providing the proper QoS degradation level in the transport network, and bandwidth limitation was set Netlimiter.

Figure 2 shows the network architectures of the experiment for both scenarios: firstly, when the 2D and 3D videos were delivered and watched on the PCs connected directly to the GPON; and secondly, when the 3D video was transferred through the GPON to clients with WiFi 802.11n access to the transport network.

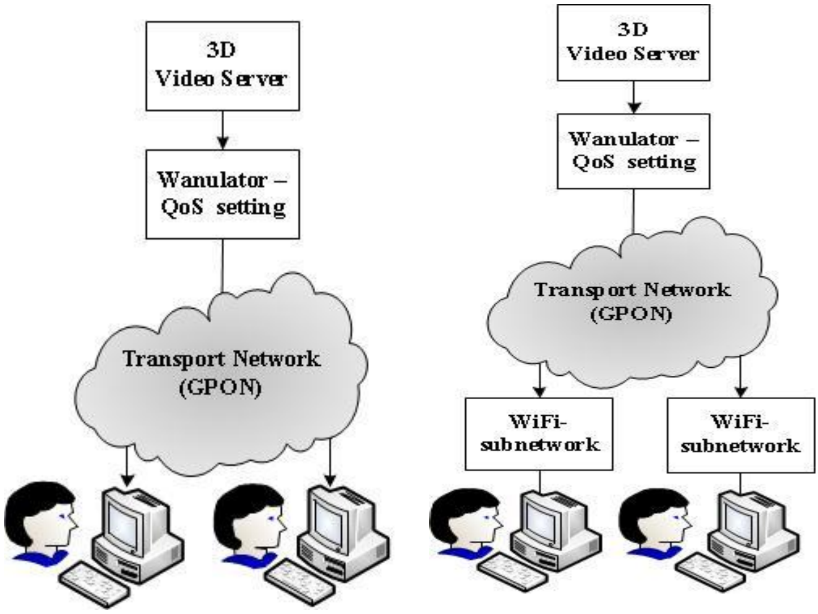

Figure 2
Network architectures of the experiment without and with the WiFi sub-networks

3 Method of Measurements

The common practice for estimating user perception from network-level performance criteria is to conduct large experiments in a controlled environment. The QoE can be affected by many factors: network features which refer to QoS metrics such as packet loss, delay, jitter, reordering, and bandwidth limitation; and also multimedia features, which include higher levels' specific parameters such as coding, quantization, bit-rate, frame-rate and motion level. All could have an effect on the QoE [12].

Mutimedia sequences (undistorted and distorted contents as well) can be scored by the Mean Opinion Score (MOS) in the case of subjective evaluation, which is the core of our experiments. The Mean Opinion Score (MOS) [17] quality scale method is typically applied for voice and video traffic scale (shown in Table 2). Reference sequence quality can be also graded by MOS for more detailed results, but usually only the outcome needs to be done.

Based on the first-hand experience of our testing [15], we prepared an investigation regarding the QoE-QoS relation not only for 3D video streams but also for 2D content as well. Our goal was to use statistical analysis to obtain more information on the relationship between the degradation of QoS parameters and QoE evaluations.

Table 2
MOS Quality Scale

Score	Sequence quality
5	Excellent
4	Good
3	Regular
2	Bad
1	Awful

In both cases (in the GPON environment and in the WiFi network topology) participants watched a short part of the 3D stereoscopic film *Avatar*, the features of which are shown in Table 3, and had to evaluate the following questions about quality during video watching focusing on the empirical quality of the video.

1) Rate continuity of the video content.
2) Rate the quality of picture. Did you notice disintegration of picture?
3) How did you assess the 3D experience on the whole?
4) How did you feel conformity between the picture and voice?
5) What was the quality like on the whole?

Table 3
Features of the investigated 3D video

Title	Video codec	Audio codec	Container format
Avatar	WMPv9 (VC-1 Simple/Main)	WMAv2	wmv
Length (mm:ss)	**Resolution**	**Video bitrate (kb/s)**	**Audio bitrate (kb/s)**
03:32	1280*720	9646	192

The order of these points was also essential. The first 4 points were about the QoE from various points of view. The last one was about QoE on the whole, which is usually much more complicated than only the recapitulation of the first 4 points. We also asked users to weight their answers for the correct statistical analysis. These weights helped us to calculate the weighted average for representation of the QoE-QoS relationship based on the subjective tests.

4 Test Results in GPON Environment

We gathered some basic demographic information. 40 users (37 men, 3 women, 16 wearing glasses, and with an average age of 22) took part in this experiment. They watched a trailer for the 3D stereoscopic film *Avatar* mentioned above and also the same part of the film in 2D. A short part was enough because the goal was the QoE estimation and not an assessment of the film content [14].

Two types of degradation were made on the 3D and 2D video file, as well. And the test users scored the videos in the case of the following scenarios via the MOS:

1) Reference undistorted video files
2) Videos disturbed only by jitter increase
3) Videos disturbed by bandwidth limitation and jitter increase

The value of bandwidth limitation was calculated based on the maximum bandwidth demand, which was around 40 Mb/s for the 3D content in the case of the highest motion level scenes. The mean value of the bandwidth used was around 32 Mb, so we set the bandwidth threshold to 32 Mb/s, which caused throughput limitation. This value was set by the Netlimiter software for each client.

Value settings of these scenarios are shown in Table 3 and Table 4.

Table 3

Parameters values for jitter degradation

QoS setting	Type of video	Values refer to every measuring	1. test	2. test	3. test	4. test
Jitter	2D	9400 packets + 470 burst for jitter; Bandwidth limit. none	Jitter: 100 ms	Jitter: 120 ms	Jitter: 140 ms	Jitter: 160 ms
	3D	9400 packets + 470 burst for jitter; Bandwidth limit. none	Jitter: 90 ms	Jitter: 100 ms	Jitter: 120 ms	Jitter: 160 ms

The results of the reference tests (watching the undistorted video file) showed that people who had watched 3D movies or videos before this experiment (36 persons) perceived the 3D content as lower quality than the rest of them (4 person). The average value of 3D experience (point 3 in the questionnaire) was 3.83 (almost 4, i.e. good quality) which was very good score on the whole.

After evaluation of the averages, we counted the weighted average based on weighted answers gathered from users, and we could assign one QoE value to every certain value of the QoS parameters. If an answer was given a larger weight by the user, this meant that this feature (one of points 1-5 above) was more important for the user. A summary of this information is shown in Table 5.

Table 4
Parameters values for throughput limitation + jitter

QoS setting	Type of video	Values refer to every measuring	1. test	2. test	3. test	4. test
Band-width limit. + Jitter	2D	9400 packets + 470 burst for jitter; Bandwidth 32 Mb/s	Jitter: 100 ms	Jitter: 120 ms	Jitter: 140 ms	Jitter: 160 ms
	3D	9400 packets + 470 burst for jitter; Bandwidth 32 Mb/s	Jitter: 90 ms	Jitter: 100 ms	Jitter: 120 ms	Jitter: 160 ms

Table 5
Summary of weighted values

3D QoS	reference	90 ms jitter	100 ms jitter	120 ms jitter	160 ms jitter
3D QoE	4,355	4,225	3,7775	2,955	2,2425
2D QoS	reference	100 ms jitter	120 ms jitter	140 ms jitter	160 ms jitter
2D QoE	4,8193	4,771	4,5199	4,143	3,1998

3D QoS	reference	90ms jitter + BW32Mb/s	100ms jitter + BW32Mb/s	120ms jitter + BW32Mb/s	160ms jitter + BW32Mb/s
3D QoE	4,355	3,625	3,205	2,395	1,8325
2D QoS	reference	100ms jitter + BW32Mb/s	120ms jitter + BW32Mb/s	140ms jitter + BW32Mb/s	160ms jitter + BW32Mb/s
2D QoE	4,8193	4,6951	4,0471	3,3898	2,7311

We can clearly recognize QoE deterioration based on an increase of QoS. Observers watched content on two PCs simultaneously and separately connected to GPON by two WiFi access points. The NVPv1.6 player was set up with 440 ms de-jittering buffer and it was not changed during the whole experiment.

Figure 3 shows QoE degradation based on jitter increase by using interpolation lines in the case of the 2D and 3D video.

Applying the method of least squares we got the next solutions:

- 2D: $1.41046 * 10^{-6} x^3 - 0.000558526 x^2 + 0.0398079 x + 4.88527$ (6)
- 3D: $4.19435 * 10^{-6} x^3 - 0.00116773 x^2 + 0.0644745 x + 4.22993$ (7)

The QoE-QoS relationship shows a cubic correlation, and the sensitivity is more pronounced in the case of 3D video.

Figure 3 shows the confidence interval (CI) of the QoE values, where the normal distribution is applied and a 90% confidence interval, and the critical value was calculated for this 90% CI. Lines of averages are plotted with bold lines and the margins of CI are plotted with dashed lines. In the case of the 3D video, the CI is more descending.

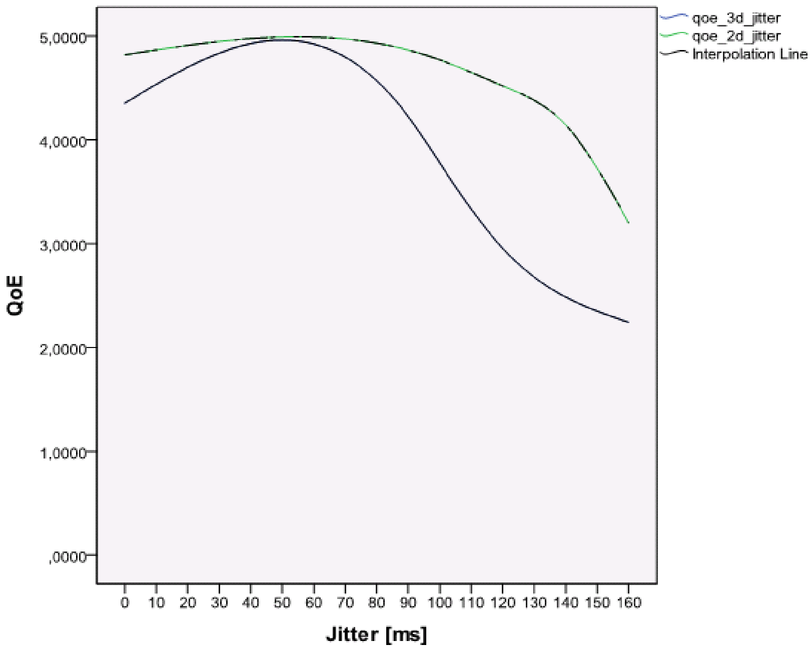

Figure 3
QoE based on jitter increase

A jitter value of 90 ms was the threshold for the 3D video, and a jitter value of 100ms was the threshold for the 2D video when the vision quality was still good, without jerkiness and freezing during the watching. The quality rapidly broke down from this point and participants were not satisfied with the quality due to jerkiness and, later, even a freezing picture. This method of evaluation was used in case of jitter increase and throughput limitation at the same time, when the threshold values were kept at 90 ms and 100 ms jitter value, but fell down rapidly from this point.

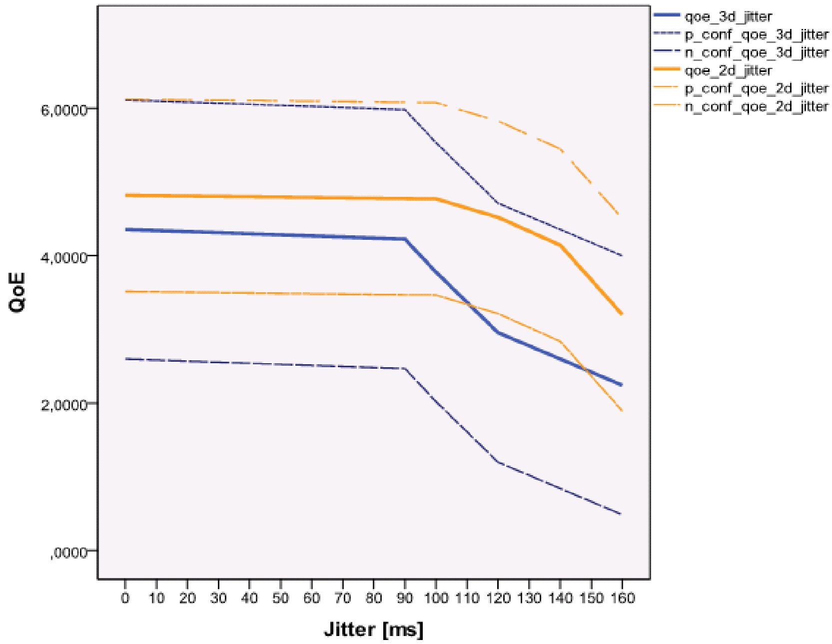

Figure 4
Confidence interval of QoE in case of jitter increase

5 Test Results in a WiFi Environment

In this experiment 36 participants attended (34 men and 2 women), who study at the Budapest University of Technology and Economics. 18 of them wore glasses, and their mean age was 22.14. The youngest student was 20 years old, while the oldest one was 27. 32 participants had watched 3D movies before the tests.

Observers watched content on two PCs simultaneously, separately connected to GPON by two WiFi access points. When people watched 3D stereoscopic content on two PCs simultaneously, playback was not fully fluent especially during higher motion level scenes, even in the case without any QoS parameter degradation in the transport. Simultaneously, two wireless configurations were investigated and loaded condition of them significantly affected our measurements, which could appear in real networks as well. Using WiFi channel-13 caused a medium load, while channel-3 showed an extremely crowded wireless condition.

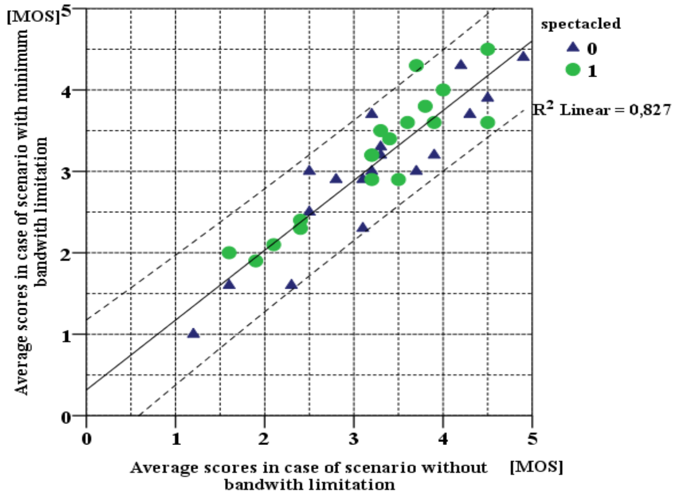

Figure 5

QoE scores comparision between scenarios with the moderate bandwidth limitation on channel-13: x-axis MOS values in case of bandwidth 40 Mb/s and y-axis MOS values in case of bandwidth value 36 Mb/s with bandwidth limitation 4 Mb/s

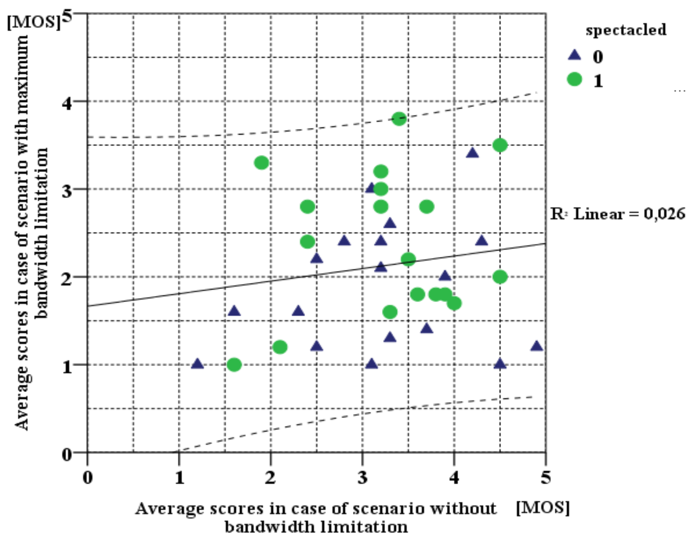

Figure 6

QoE scores comparision between scenarios with the high bandwidth limitation on channel-13: x-axis MOS values in case of bandwidth 40 Mb/s and y-axis MOS values in case of bandwidth 28 Mb/s with bandwidth limitation 12 Mb/s

Figure 5 shows linear regression with small deviation between average scores based on observation results in the case of small QoS degradation. This means that only small differences appeared in scoring between intact and moderately limited playback. In the second case, the video was played back with small QoS degradation, namely the bandwidth was limited with 4 Mb/s compared to the intact situation. Bandwidth limitation values were calculated on the average demand bandwidth value of the 3D stream, which during 95% of the playing time was 32 Mb/s, except in case of the highest motion level scenes when spine values appeared, exceeded this 32 Mb/s value up to 40 Mb/s. According to our experiments, with respect to the offered load, 40 Mb/s was considered as the highest load in the network, thus considered as an intact situation. During the tests, bandwidth in the transport was limited. The threshold was set to 36 Mb/s when the bandwidth limitation was 4 Mb/s, and so on, which caused network QoS degradation during our experiments.

Figure 6 shows a comparison of the results in the intact case and the highest bandwidth limitation setting when the bandwidth threshold value was 28 Mb/s with bandwidth limitation of 12 Mb/s. As we can see, the linearity disappeared in this case. When the quality of continuity became unacceptable because of jerkiness and freezing, some participants' average score still remained above 3 (regular quality). As can be seen in the figure, these participants were mostly with glasses, and they did not assess the poor quality so critically.

Also, it is observation that only spectacled people scored better the playback with higher bandwidth limitation in both cases depicted in Figure 5 and Figure 6.

In the article [12], the IQX hypothesis is presented, which is a natural and generic relationship between QoE and QoS. They demonstrated the feasibility of exponential relationship through a couple of case studies, for example measurements results for web browsing in a fast network taken from G.1030. Our experiments show correlation with quadratic and even with cubic model is much better than applying exponential model assuming the limitations of moderate and high crowded channel, channel 3 and channel 13, respectively. The applied models are shown in Figure 7 and Figure 8. This means that the QoE-QoS relationship for 3D stereoscopic video playback shows cubic correlation with R square of 0.964 on channel 3.

We can recognize a bigger contrast in the case of channel 13, as shown in Figure 8, where a higher QoE were evaluated with better scores at the beginning, but from the threshold bandwidth limitation value of 8Mb/s, a stronger QoE decrease appeared. The QoE-QoS relationship also shows a cubic correlation with R square 0.993. This difference from the logarithmic approaches found in [18] [19] and the correlation model proposed in [12] is caused by 3D video content specifics compared to data centric QoE observations.

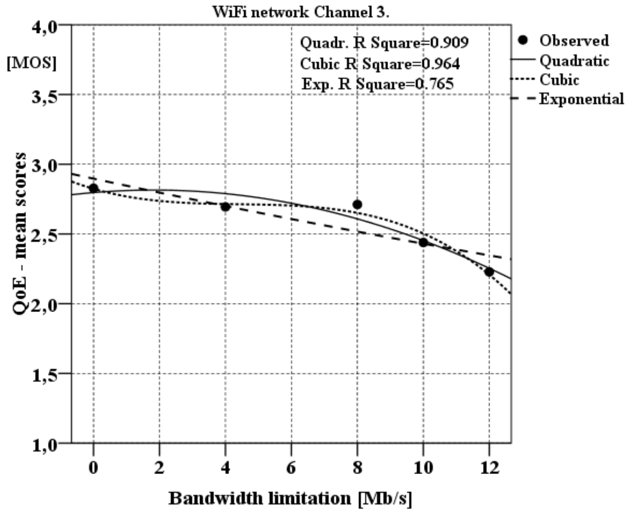

Figure 7

QoE mean scores results for 3D video watching carried on channel 3 and compared with quadratic model, cubic model, and exponential model

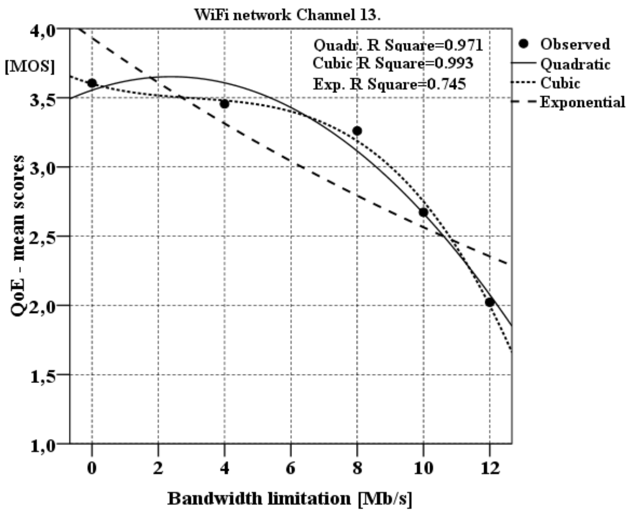

Figure 8

QoE mean scores results for 3D video watching carried on channel 13 and compared with quadratic model, cubic model, and exponential model

In the case of services such as video transport, continuity is the most significant factor in the case of QoE evaluation. We can recognize it from Figure 9, which shows in detail the evaluation of QoE degradation caused by bandwidth limitation for each question. From the boxplots the following observations can be made.

1) The rate of continuity was scored the most critically because the highest mean score was only 2.5 (between regular and bad), which was caused by data sequences stuck during high motion level parts of video. The threshold bandwidth limitation value was 8 Mb/s. In the case of 10 Mb/s and 12 Mb/s limitation values, the quality of continuity was unacceptable because of the jerkiness and freezing which occurred during playback.

2) The quality of picture was scored much better than continuity, usually between 4 and 3 (good and regular quality), because blurriness did not appear during the experiment, even in the worst case.

3) *The assessment of the 3D experience on the whole* was not so much criticized as the continuity, and the best mean score was 3 - good even for 4 Mb/s limitation. This point is interesting, because this means people are still accustomed to 2D screening, and they are more tolerant in the case of 3D quality impairment than in the case of video continuity stalling or short jerkiness. And the 3D QoE, such as the depth of picture, was not so sensitive to the QoS degradation than the screening continuity.

4) *Conformity between picture and voice* was scored with the biggest deviation and was acceptable, except in the last two scenarios with 10 Mb/s and 12 Mb/s bandwidth limitation values, when due to heavy continuity degradation, voice quality also rapidly fell off.

5) *The quality of 3D video watching, like as on the whole*, was scored with big deviation even in case of no bandwidth degradation. Some people scored it with 4 (good) but some even with 2 (bad); therefore, even the best mean score is only under three (less than regular quality), representing the most subjective part of the experiments.

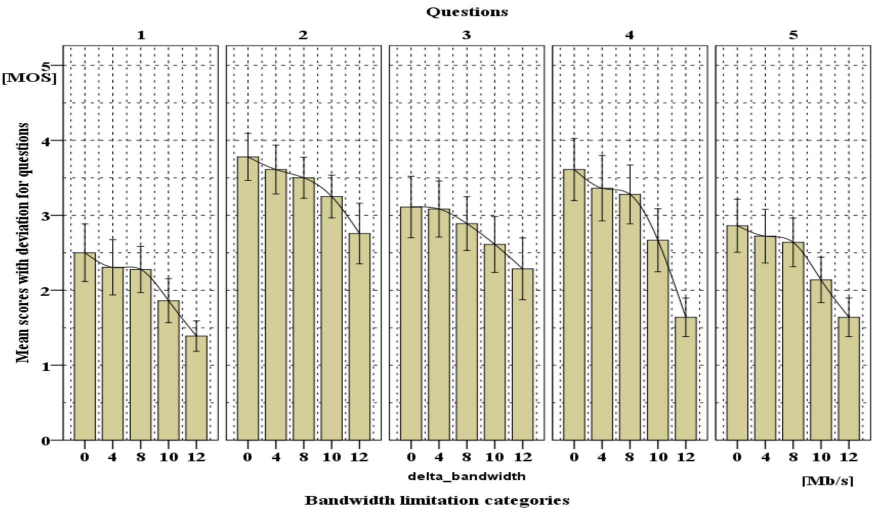

Figure 9

Boxplots mean scores with deviation for each bandwidth limitation values separately and clustered by questions: 1-continuity, 2-quality of picture, 3-3D experience, 4-conformity between picture and voice, 5-3D video vision quality on the whole

Consequently, participants were the most sensitive to the fluidness and continuity of scenes, and the 3D experience was less important when they evaluated the subjective video quality.

Conclusion

Within this paper a complex subjective test method of QoE investigation of 3D stereoscopic video files has been introduced. The GPON network, with its capacity, was suitable for the efficient transport of these contents even in unicast mode.

Firstly, the relationship between the QoE and QoS was shown based on the gathered results for 3D stereoscopic multimedia content, compared with results of the 2D implementation of the same content. The evaluation of data was carried out by IBM Statistics software. QoS metrics such as jitter and throughput limitation disturbance were demonstrated by tests results which showed cubic correlation in both cases. The quality of 3D presentation, such as depth impression, is influenced by multimedia features as well, and dynamic, high-movement sections in video are more sensitive to the QoS degradation.

In Future Internet research, one significant concept is to obtain network neutrality by extending of heterogeneity in the network architecture and service support. In the second part of this article are presented some results of subjective test results of the QoE-QoS relationship character with 36 participants in suitable environment representing a common future environment, the GPON-based transport network + WiFi sub-network based on IEEE 802.11n in the 2.4 GHz band on the client side. Characteristics of QoE degradation were shown and analyzed on gathered MOS scores of participant experiments. The good quality guarantee is more complex in the case of WiFi access because the QoE is influenced by the nature of wireless technology (such as bandwidth limitation of multiple clients or channel interferences) and by the QoS level in transport network, as well. Robustness of 3D content, QoS degradation and limitation of WiFi network together cause stronger QoE deterioration on the client side.

The goal was to compare gathered experiments with exponential fitting function based on the IQX hypothesis [12] in the case of vision quality investigation of 3D stereoscopic video delivery through a WiFi network. Applying the cubic fitting function to measurement results leads to better correlation with *R Square* values *0.964* and *0.993* than exponential fitting function with *R Square* values *0.765* and *0.745* in the investigated bandwidth limitation interval. This different result was caused by 3D video content delivery service investigation and subjective QoE assessment by users.

Our results show that the fluidness and permanent continuity of video-streams is the most important aspect for good QoE. The primary importance of QoE investigation in wireless network environments has came to the forefront due to worldwide growth of video-stream presentation on smart small mobile devices, and results of this contribution could be helpful for ISPs in the case of 3D based multimedia services.

In the future, more measurements and investigation are needed with various QoS disturbances such as delay, jitter and packet loss in a wireless environment and with explicit channel parameters such as WiFi Access Category, Beacon time, Max. Agg. Frames as long as the resulting A-MPDU fits within the configured TXOP limit, etc. considered. The goal is the mathematical modeling of the functional relationship between QoE and QoS metrics, which is needed for an optimal solution of 3D stereoscopic video contents delivery with appropriate display quality.

Acknowledgement

This work was supported by NKTH-OTKA grant CNK77802.

References

[1] Jianli Pan; Paul, S.; Jain, R.; "A Survey of the Research on Future Internet Architectures," Communications Magazine, IEEE, Vol. 49, No. 7, pp. 26-36, July 2011 doi: 10.1109/MCOM.2011.5936152

[2] Zahariadis T., Daras P., Laso-Ballesteros I. „Towards Future 3D Media Internet” Network & Electronic Media – Summit, St. Malo France, October 2008

[3] Casas P., Belzarena P., Vaton S. „End-2-End Evaluation of IP Multimedia Services, a User Perceived Quality of Service Approach” 18th ITC Specialist Seminar of Quality of Experience, Karlskrona, Sweden, May 2008, pp. 13-23

[4] Mrak M., Grgic M., Kunt M. High-Quality of Visual Experience, Chapter 3, You J., Xing L., Perkis A. „Quality of Visual Experience for 3D Presentation – Stereoscopic Image” Signals and Communication technology, 2010, I, pp. 51-77

[5] Kroeker L. Kirk „Looking beyond Stereoscopic 3D’s Revival” Communications of the ACM, Volume 53, Issue 8, August 2010, pp. 14-16

[6] Xing L., You J., Ebrahimi T., Perkis A. „Estimating Quality of Experience on Stereoscopic Images” ISPACS 2010 – International Symposium on Intelligent Signal Processing and Communication Systems, Chengdu, December 2010

[7] Cale I., Salihovic A., Ivekovic M. „Gigabit Passive Network – GPON” ITI 2007 – International Conference on Information Technology Interfaces, Cavtat, Croatia, June 2007, pp. 679-684

[8] Zilly F., Müller M., Eisert P., Kauff P. „The Stereoscopic Analyzer – An Image-based Assistance Tool for Stereo Shooting and 3D Production” ICIP 2010 – IEEE International Conference, Hong Kong, September 2010

[9] Häkkinen J., Kawai T., Takatalo J., Leisiti T., Radun J., Hirsaho A., Nyman G. „Measuring Stereoscopic Image Quality Experience with Interpretation Based Quality Methodology” IS&T/SPIE’s International Symposium on Electronic Imaging, San Jose, California USA, January 2008

[10] Lambooij M., Ijsselsteijn W., Heynderickx I., „Visual Discomfort in Stereoscopic Displays: A Review” Journal of Imaging Science and Technology - May/June 2009, Volume 53, Issue 3, pp. 030201-(14)

[11] Shibata T., Kurihara S., Kawai T., Takahashi T., Shimizu T., Kawada R., Ito A., Häkkinen J., Takatalo J., Nyman G. „Evaluation of Stereoscopic Image Quality for Mobile Devices Using Interpretation-based Quality Methodology” Proc. SPIE, Vol. 7237 (2009)

[12] Fiedler M., Hossfeld T., Phuoc Tran-Gia „A Generic Quantitative Relationship between Quality of Experience and Quality of Service” IEEE Network, March/April 2010, Volume 24, Issue 2, pp. 36-41

[13] Fort S. „2020 3D Media: New Directions in Immersive Entertainment” SIGGRAPH 2010 – International Conference and Exhibition on Computer Graphics and Interactive Techniques, Los Angeles, USA, July 2010

[14] Quin Dai „A Survey of Quality of Experience” In. Ralf Lehnert (Ed.) EUNICE 2011, LNCS, Vol. 6955, pp. 146-156 Springer, Heidelberg (2011)

[15] Kulik I., Trinh T. A. „Investigation of Quality of Experience for 3D Streams in GPON” In. Ralf Lehnert (Ed.) EUNICE 2011, LNCS, Vol. 6955, pp. 157-168 Springer, Heidelberg (2011)

[16] Milton J. S., Arnold J. C. „Probability and Statistics in the Engineering and Computing Sciences” McGraw Hill International Editions (1986)

[17] International Telecommunication Union (2003) ITU-T Recommodation P.800.1: Mean Opinion Score (MOS) termonilogy

[18] ITU-T Rec. G.1030, “Estimating End-to-End Performance in IP Networks for Data Applications,” Nov. 2005

[19] S. Khirman and P. Henriksen, “Relationship between Quality-of-Service and Quality-of-Experience for Public Internet Service,” 3rd Passive Active Measurement Wksp., Fort Collins, CO, March 2002

[20] Rugel S., Knoll T. M., Eckert M., Bauschert T. „A Network-based Method for Measuring of Internet Video Streaming Quality” 1st European Teletraffic Seminar, Poznan, Polland, February 2011

[21] International Telecommunication Union, “Subjective Video Quality Assessment Methods for Multimedia Applications”, rec. ITU-T P.910, 1999

[22] Garroppo R., Giordano S., Oppedisano F., Procissi G., “A Receiver Side Approach for Real Time Monitoring of IP Performance Metrics”, Proc. of the EuroFGI Workshop on IP QoS and Traffic Control, pp. 169-176, 2007

[23] ur Rehman Laghari K., Crespi N., Molina B., Palau C. E. , "QoE Aware Service Delivery in Distributed Environment", Advanced Information Networking and Applications (WAINA) 2011 IEEE Workshops of International Conference on, Vol., No., pp. 837-842, 22-25, March 2011

[24] Zheng H., Boyce J., "An Improved UDP Protocol for Video Transmission over Internet-to-Wireless Networks", Multimedia, IEEE Transactions on, Vol. 3, No. 3, pp. 356-365, Sept. 2001