Budapesti Műszaki Egyetem

Távközlési és Médiainformatikai Tanszék

3 dimenziós videó-folyamok QoE vizsgálata a QoS függvényében

Pro Progressio alapítvány számára készítette:

Kulik Ivett

mérnök

Budapest

2011. december

Abstract: *In this paper a statistical analysis of subjective perception of 3D video streams' Quality of Experience (QoE) are shown. The Gigabit Passive Optical Network (GPON) is suitable for efficient transport of 3D multimedia contents that can carry bandwidth-extensive 3D video stream-based applications and contents. Data were gathered through real GPON-based transport network measurements focusing to relationship between QoE and network level QoS. Our results show that our investigated scenarios' QoE results of 3D video streams watching are dependent on the network caused QoS and some multimedia features as well. Because subjective test were carried out for 2D type of visualization of same video contents as well, finally the 2D and 3D investigation results are also compared statistically.*

Keywords: *3D stereoscopic video streams, Quality of Experience-QoE, Quality of Service-QoS, GPON-based network, Mean Opinion Score-MOS, subjective evaluation, IBM SPSS, statistics*

1 Introduction

The worldwide increasing of multimedia contents' transmission and especially the increase of three dimension video services have become challenging issues for Internet Service Providers (ISPs). A seamless delivery of 3D video streams means that the provider needs to be able to observe and react quickly on 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 are 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.

The Future 3D Media Internet is a significant part of research work, which should be designed to overcome current limitations involving network architecture, content and service mobility, new forms of 3D content provisioning etc. [1], [4]. Investigation of QoE in multimedia services can be performed either by subjective or objective methodologies. Subjective tests are carried out by tests of real users and objective tests are carried out by an algorithm on behalf of real users, trying to predict user perception based on key properties of the reference or the outcome [2].

Obviously network level QoS parameters like throughput, delay, jitter and packet loss affect user level QoE parameters. Observation of this issue is very important. This paper shows assessment of subjective QoE measuring of 3D stereoscopic video file based on Gigabit Passive Optical Network (GPON) transport network in laboratory environment. The QoE estimating of stereoscopic video streams carried out and results are available in previous publications [5], [8] and quality of presentation became important on mobile devices as well [10].

At first we carried out experiments based on subjective testing of 3D video files where fifty participants could observe QoE changing due to degradation of QoS parameters [14]. We went on our experiments and this paper contents results of second part of our investigation carried out other subjective testing of QoE – QoS relationship where one video file was observed in 3D and 2D type of visualization as well. Fourty users watched videos with various QoS degradations and with several change of video parameters. People scored their experience based on Mean Opinion Score (MOS). The GPON transport network was suitable for efficient transport of multimedia contents but the QoE declined due to degradations. Gathered information were evaluated and compared by the IBM SPSS Statistics software.

The paper is structured as follows. In Section 2 we explain relationship between QoE and QoS based on statistics. Section 3 contains description of measurements' process. Section 4 shows detailed explanation of statistically evaluated results. Finally this paper is concluded in Section 5.

2 Aproaching of relationship between QoE and QoS based on statistics

There has always been a gap of perception between the ISPs and theirs customers when talking about the good quality of network service. The reason is that providers and customers use different criteria. The network level QoS parameters are used by ISPs for measuring of service performance and the user level approach like subjective perception, usually called QoE, is more important for users [13].

QoS parameters like throughput, delay, jitter and packet loss can be measured on customers' nodes or also between two provider's devices and are part of technical concept of service quality. QoE which is non-technical information reflects to the user satisfaction itself. QoE can be potentially affected by network factors like QoS but by the multimedia attributes like coding, bit-rate, frame-rate and motion level as well. Expectations of users and the video content itself also could have an effect on QoE.

2.1 Quality Comparisons and Classification of Metrics

Obviously generic QoS problems imply QoE problems as well. Thus the investigation of relationship between QoE and QoS is still a relevant issue.

The derivation of QoE-QoS relationships builds on quality comparisons between:

- The ***reference*** - which is the undistorted video stream
- The ***outcome*** – which is the potentially distorted video stream due to the QoS degradation

References play an important role when it comes to rating the quality of outcome. There are two basic measurement options: subjective tests and objective tests [11].

Subjective tests are carried out by real users and this type of test is time consuming because a large number of people have to participate on it for statistically relevant results.

Objective tests are carried out by an algorithm following psychophysical and engineering approaches without human presence.

Type of QoE-QoS relationships metrics can be:

Full reference metrics – which allow detailed subjective and objective comparisons of multimedia contents because both reference and outcome are available.

No reference metrics – which is an online situation where no reference is available and quality results can be extracted only from the outcomes.

Reduced reference metrics – which is not so detailed comparison than the case of full reference metrics but here the same set of parameters are derived and compared for the reference and outcome as well.

Table 1 MOS Quality Scale

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

Mutimedia sequences (undistorted and distorted contents as well) can be scored by the Mean Opinion Score (MOS) in case of subjective evaluation, which is the core of our experiment and this paper. The Mean Opinion Score (MOS) quality scale method used to be applied for voice and video traffic scale (shown in Table 1). Reference sequence's quality can be also grade by MOS for more detailed results but usually only outcome has to be done.

2.2Basic Categories of Statistics

Statistics is the scientific discipline that provides methods to help us make sense of data. Statistics also help to collect data in a sensible way and help to describe analyze and draw conclusions from data by a set of powerful tools. The goal of analysis is to make correct judgments and decisions in the presence of uncertainty and variation and to detect relations between data [15]. The statistics methodology is founded on the probability study.

Definitions:

The entire collection of individuals or objects about which information is desired is called the **population** of interest. A **sample** is a subject of the population, selected for study. X_i is the i-th element of sample.

A **variable** is any characteristic whose value may change from one individual or object to another.

A study is an **experiment** if the investigator observes how a response variable behaves when one or more explanatory variables, also called factors, are manipulated.

Mean: $\frac{1}{n}\sum_{i=1}^{n} x_i$ (1)

Median: $\begin{Bmatrix} x^*_{n+1} \text{ ,} if\ \ n\ is"odd" \\ \frac{x^*_n + x^*_n}{2} \text{ ,} if\ \ n\ is"even" \end{Bmatrix}$ (2)

Deviation: $\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \overline{x}\right)^2}$ (3)

Variance: $\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \overline{x}\right)^2$ (4)

In our experiments QoE was the response variable, scored by the MOS, and QoS parameters like jitter degradation and bandwidth limitation were explanatory variables.

The method of **least squares** is a standard approach to the approximate solution for sets of equations in which there are more equations than unknowns. "Least squares" means that the overall solution minimizes the sum of the squares of the errors made in solving every single equation.

A **confidence interval** is a particular kind of interval estimate of a population parameter and is used to indicate the reliability of an estimate. It is an observed interval that frequently includes the parameter of interest, if the experiment is repeated. How frequently the observed interval contains the parameter is determined by the **confidence level** or **confidence coefficient**.

2.3IBM SPSS Statistics software

Collected data were analyzed by the IBM SPSS Statistics software-package for business, government, research and academic organizations. SPSS is an abbreviation for Statistical Package for Social Scientists but the other name: Statistical Product and Service Solutions is also well-known.

The IBM SPSS Statistics Standard Edition offers the advanced statistical procedures to make analysis more reliable, to get a quick look at our data, formulate hypotheses for additional testing, and then carry out a number of procedures to help clarify relationships between variables, create clusters, identify trends and make predictions. Key capabilities include:

Linear models: The SPSS Statistics includes a variety of regression and advanced statistical procedures designed to fit the inherent characteristics of data describing complex relationships, including General linear models (GLM), Generalized linear mixed models (GLMM), Generalized linear models (GENLIN) and Generalized estimating equations (GEE)

Nonlinear models: We can also apply more sophisticated models to our data using a wide range of nonlinear regression models, using procedures: Multinomial logistic regression (MLR), Binary logistic regression, Nonlinear regression (NLR) and constrained nonlinear regression (CNLR), Probit analysis.

3 Subjective testing of 3D video streams

Stereoscopic imaging is a technique capable of recording 3D visual information or creating the illusion of depth. Most 3D compression schemes apply two-dimensional compression techniques and consider theories of binocular suppression as well [3], [9].

The common practice to estimate 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 packet loss, delay, jitter, reordering, bandwidth limitation and also multimedia features which include higher levels' specific parameters like: coding, quantization, bit-rate, frame-rate and motion level could have an effect on the QoE [11].

Based on the first hand experience of our testing [14] we prepared a new investigation about QoE QoS relation not only for 3D video streams but for 2D contents as well. Our goal was to carry out more information of QoE behaviour by more QoS parameters'degradation and find relationship by statistical analysis between them. Comparison of 3D and 2D results was done as well.

3.1The GPON-based transport network

The GPON based transport network was efficient with 2.5Gbit/s download speed and 1.5Gbit/s upload speed in laboratory [6] by providing broadband and responsible access to video server with 3D multimedia streams. Video contents had to be transfer in unicast mode to clients instead of multicast mode because of the Nvidia Vision Player which could play only stereoscopic 3D streams delivered in unicast mode and based on TCP transport at this time. Hardware configuration of clients is shown in the Table 1.

The whole GPON-based network architecture is shown in Figure 1. The transmission network consist 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 and 1:4. The OLT and ONT devices are managed by the Siemens EM-PX manager client.

Table 1 Hardware configuration of the client for videos presentation

	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	

Video server was responsible for 3D and 2D video files storing and sharing, what was guaranteed by the VLC program.

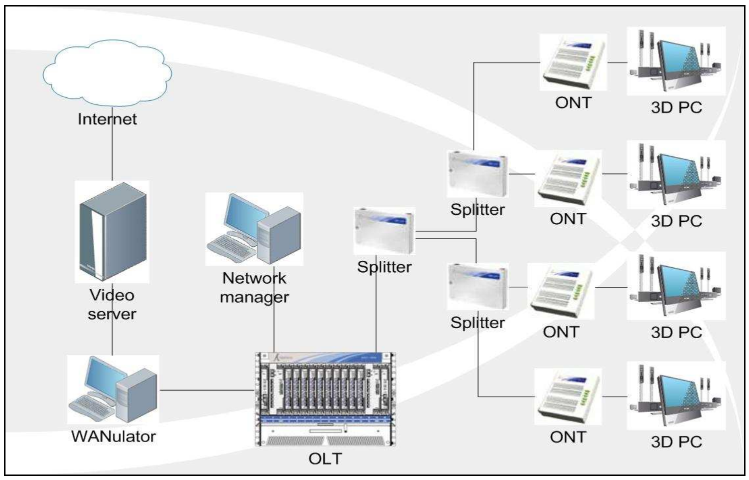


Figure 1 The GPON-based network for 3D video streams investigation

The WANulator software simulates different Internet conditions such as delay, jitter or packet loss providing the proper QoS degradation level in the transport network for the experiment.

3.2Procedure of Measurement

We gathered some basic demographic information. Forty users (37 men, 3 women, 16 spectacled from them and with average age 22) attended our experiment. They watched a short part of 3D stereoscopic Avatar film and also the same part of film in the 2D implementation. A short part was enough because the goal was the QoE estimation and no the content assessment [13].

Four type of degradation was made on the 3D and 2D video file as well. And test users scored videos in case of follow scenarios by means of the MOS:

1. Reference undistorted video files
2. Videos disturbed only by jitter increase

3. Videos disturbed by bandwidth limitation and jitter increase
4. Videos disturbed by changing of quantization
5. Videos disturbed by changing of video bit-rate

Participants had to evaluate some points. They had to answer questions below:

- Rate the video continuity!
- Rate the quality of picture ("checked" or "dimmer" picture)!
- Rate the 3D Quality of Experience!
- Rate the conformity between the picture and voice!
- Rate the Quality of Experience on the whole!

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

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

Table 2 Features of the investigated 3D video

Table 2 is showing basic features of the investigated 3D video. Users watched short part from this trailer which included lower and higher motion level parts as well.

The reference test was very important compare point for measuring with QoS degradations.

Jitter degradations were set by the WANulator software with values which could be used for testing of 3D and 2D presentation of video file as well.

The value of bandwidth limitation was calculated based on the real maximum bandwidth demand which was around 7.5MB for the 3D content. The mean value of used bandwidth was around 4 MB, so we set the bandwidth threshold to 4MB. This value was set by the Netlimiter software on the each client.

Value settings of these two scenarios are shown in the next tables:

Table 3 Values of parameters for Scenario 1 (jitter changing)

QoS setting	Type of video	Values refer to every measuring	1. test	2. test	3. test	4. test
Jitter	**2D**	Quantization: 2; bitrate 11000 kb/s 9400 packets + 470 burst for jitter; Bandwidth limit. none	Jitter: 100 ms	Jitter: 120 ms	Jitter: 140 ms	Jitter: 160 ms
	3D	Quantization: 2; bitrate 24000 kb/s 9400 packets + 470 burst for jitter; Bandwidth limit. none	Jitter: 90 ms	Jitter: 100 ms	Jitter: 120 ms	Jitter: 160 ms

Table 4 Values of parameters for Scenario 2 (bandwidth limit. + jitter changing)

QoS setting	Type of video	Values refer to every measuring	1. test	2. test	3. test	4. test
Band-width limit. + Jitter	2D	Quantization: 2; bitrate 11000 kb/s 9400 packets + 470 burst for jitter; Bandwidth limit.: 4 MB/s	Jitter: 100 ms	Jitter: 120 ms	Jitter: 140 ms	Jitter: 160 ms
	3D	Quantization: 2; bitrate 24000 kb/s 9400 packets + 470 burst for jitter; Bandwidth limit.: 4 MB/s	Jitter: 90 ms	Jitter: 100 ms	Jitter: 120 ms	Jitter: 160 ms

Quantization and video bit-rate variation could also have an effect on QoE therefore we carried out some tests with these parameters' changing as well.

Value settings of these two scenarios are shown in the next tables:

QoS setting	Type of video	Values refer to every measuring	1. test	2. test	3. test	4. test
Quanti-zation	2D	Quantization ***variable*** Bit-rate 11000 kb/s Jitter NONE; Bandwidth limit. NONE	Quant.: 10	Quant.: 15	Quant.: 25	Quant.: 40
	3D	Quantization ***variable*** Bit-rate 24000 kb/s Jitter NONE; Bandwidth limit. NONE	Quant.: 10	Quant.: 15	Quant.: 25	Quant.: 40

Table 5 Values of parameters for Scenario 3 (quantization changing)

QoS setting	Type of video	Values refer to every measuring	1. test	2. test	3. test	4. test
Bit-rate	**2D**	Quantization: 2; Bit-rate ***variable*** Jitter NONE; Bandwidth limit. NONE	Bit-rate: 6000 kb/s	Bit-rate: 4000 kb/s	Bit-rate: 3000 kb/s	Bit-rate: 2000 kb/s
	3D	Quantization: 2; Bit-rate ***variable*** Jitter NONE; Bandwidth limit. NONE	Bit-rate: 8000 kb/s	Bit-rate: 600 kb/s	Bit-rate: 5000 kb/s	Bit-rate: 4000 kb/s

Table 6 Values of parameters for Scenario 3 (bit-rate changing)

Users had to watch 16-times the part of 3D video and also 16-times the part of 2D video. The whole measurement took up 45 minutes with questionnaire filling in for each one of them.

4 Results

Appropriate statistical analysis was made after convenient ordering of gathered data. Results of reference tests (undistorted video files) showed that people who had watched 3D movie or video before this experiment (36 person) perceived the 3D contents less qualitative than the rest of them (4 person). The average value of 3D experience (3. point in the questionnaire) was 3.83 – which was very good score on the whole.

After evaluation of averages we counted the weighted average based on weights information gathered from users.

The formula of weighted average is:

$$Weighted\ average = \sum_{i=1}^{5} \frac{Weight_i * Value_i}{Sum\_of\_Weights} \qquad (5)$$

Where: i - sequential number of the appropriate questionnaire point

Sum_of_Weights – sum of weights for 3D video; sum of weights without 3. point for 2D video.

If we calculate with weighted average of measurement values we can assign one QoE value to every certain value of QoS parameters. Summary of these information are shown in the Table 7.

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 +band.limit**	**100ms jitter +band.limit**	**120ms jitter +band.limit**	**160ms jitter +band.limit**
3D QoE	4,355	3,625	3,205	2,395	1,8325

2D QoS	reference	100ms jitter +band.limit	120ms jitter +band.limit	140ms jitter +band.limit	160ms jitter +band.limit
2D QoE	4,8193	4,6951	4,0471	3,3898	2,7311
Quantiz.	reference	10	15	25	40
3D QoE	4,355	4,1725	3,7525	3,3675	3,0525
2D QoE	4,8193	4,0242	3,763	3,3355	3,0823

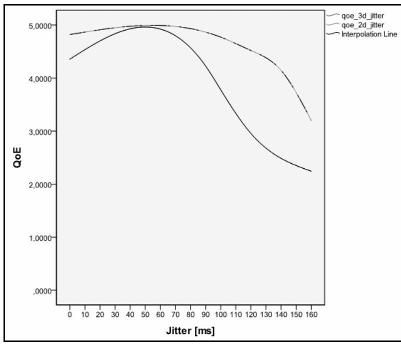
3D bitrate	reference	8000 kbit/s	6000 kbit/s	5000 kbit/s	4000 kbit/s
3D QoE	4,355	4,435	4,0425	3,625	3,3725
2D bitrate	reference	6000 kbit/s	4000 kbit/s	3000 kbit/s	2000 kbit/s
2D QoE	4,8193	4,7011	4,3237	3,8114	3,3807

Table 7 Summary of weighted values

We can clearly recognize QoE deterioration based on increase of QoS parameters or quantization and video bit-rate changing as well. An important point is the beginning of video playing by Nvidia software. 2D presentation started in 900 ms from the player start and the 3D presentation started in 440 ms from the player start.

4.1Scenario 1

Figure 2 shows relationship between QoE degradation and jitter increasing by using interpolation lines. Polynomial regression was used by for the interpolation by the SPSS. But because the SPSS did not give us mathematical description of these lines therefore the mathematical descriptions were calculated by the Wolfram Alpha application.



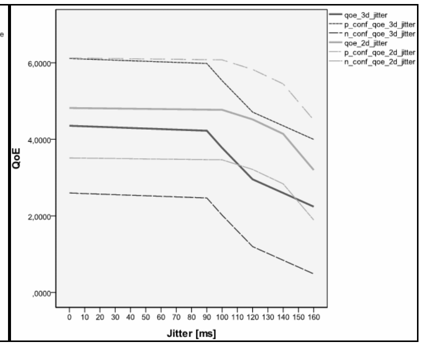


Figure 2 QoE based on jitter increase

Figure 3 Confidence interval of QoE values

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)

In case of 3D video the sensibility is more conspicuous.

Figure 3 shows confidence interval (CI) of QoE values. Because we do not know the type of distribution we presuppose normal distribution and 90% confidence interval. The critical value was calculated for this 90% CI:

$$X_j \in N(m_j, \sigma_j) \quad (8)$$

$$P\left(\left|\frac{X_j - m_j}{\sigma_j}\right| < t_{1.96}\right) = 0.9 \le 2 * \Phi(1.96) - 1 \quad (9)$$

$$\Phi(1.96) = 0.95 \quad (10)$$

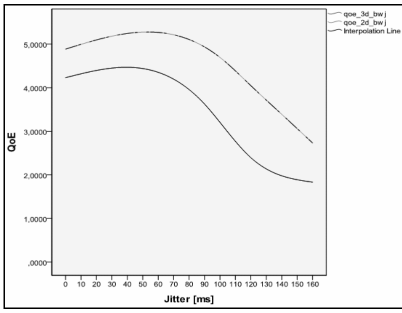
$$1.96 * \sigma_j \quad (11)$$

The deviation of appropriate variable and the critical value multiplied together gives the confidence interval. This CI is shown on the Figure 3 for 3D and 2D video file as well. Lines of averages are plotted with bold lines and margins of CI are plotted with dashed lines. In case of 3D video the CI is more descending.

These methods of calculation were also used for the other scenarios.

4.2Scenario 2

Figure 4 shows relationship between QoE degradation and bandwidth limitation (4MB/s) with jitter increasing by using interpolation lines. The mathematical descriptions were calculated by the Wolfram Alpha application.



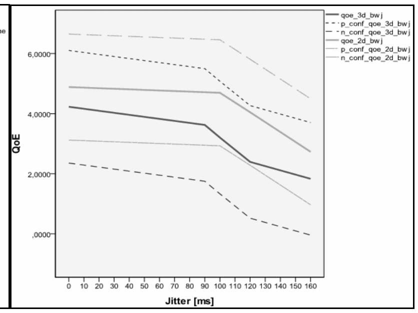


Figure 4 QoE based on 4MB/s limit+jitter

Figure 5 Confidence interval of QoE values

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

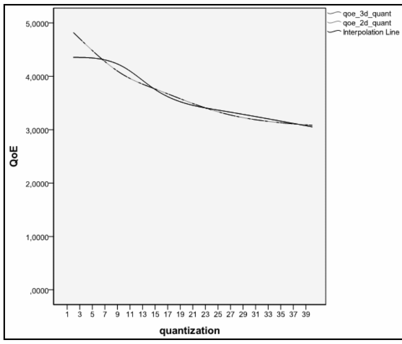
- 2D: $1.41046*10^{-6}x^3 - 0.000558526x^2 + 0.0398079x + 4.88527$ (12)
- 3D: $4.19435*10^{-6}x^3 - 0.00116773x^2 + 0.0644745x + 4.22993$ (13)

In case of 3D video the sensibility is also more conspicuous.

Figure 5 shows confidence interval (CI) of QoE values. Because we do not know the type of distribution we presuppose normal distribution and 90% confidence interval. The critical value was calculated with the same method for this 90% CI like in case of Scenario 1. The calculated CI is shown on the Figure 5 for 3D and 2D video file as well. Lines of averages are plotted with bold lines and margins of CI are plotted with dashed lines. In this case the shape of CIs of 2D and 3D video are more similar than in case of Scenario 1.

4.3Scenario 3

Figure 6 shows relationship between QoE degradation and quantization increasing by using interpolation lines. The mathematical descriptions were calculated by the Wolfram Alpha application.



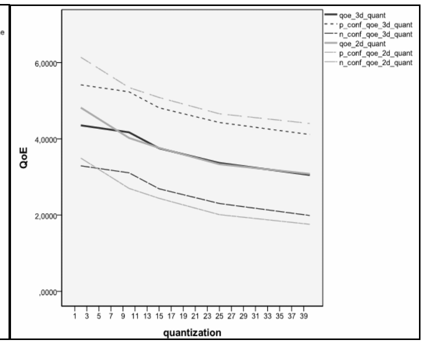


Figure 6 QoE based on quantization **Figure 7 Confidence interval of QoE values**

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

- 2D: $-0.0000289845x^3 + 0.00315821x^2 - 0.129429x + 5.06012$ (14)
- 3D: $0.0000445353 * x^3 - 0.00229913x^2 - 0.0130473x + 4.4062$ (15)

In this case the QoE sensibility is almost same for the 2D and 3D videos.

Figure 7 shows confidence interval (CI) of QoE values. Because we do not know the type of distribution we presuppose normal distribution and 90% confidence interval. The critical value was calculated with the same method for this 90% CI like in case of Scenario 1. The calculated CI is shown on the Figure 7 for 3D and 2D video file as well. Lines of averages are plotted with bold lines and margins of CI are plotted with dashed lines. In this case shapes of CIs are more similar than in Scen.1 and 2. The biggest QoE sensibility was in quantization interval (10 – 25).

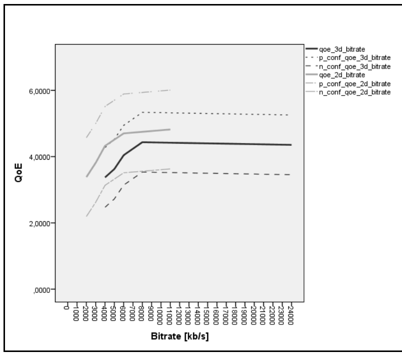
4.4Scenario 4

Figure 8 shows relationship between QoE degradation and video bit-rate changing. Mathematical descriptions were calculated also by the Wolfram Alpha.

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

- 2D: $8.6472 * 10^{-9} x^2 + 0.0000145428 \ x + 4.81866$ (16)
- 3D: $4.02225 * 10^{-9} x^2 + 0.0000693766 \ x + 4.35496$ (17)

In this case the QoE sensibility for 3D video is like shaped than for the 2D one.



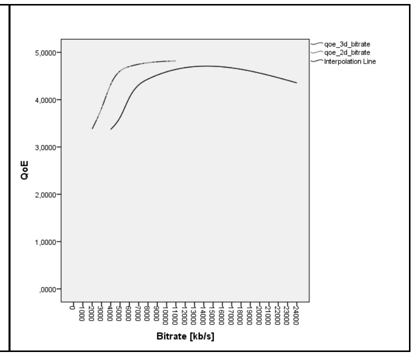


Figure 8 QoE based on quantization

Figure 9 Confidence interval of QoE values

Figure 9 shows confidence interval (CI) of QoE values. Because we do not know the type of distribution we presuppose normal distribution and 90% confidence interval. The critical value was calculated with the same method for this 90% CI like in case of Scenario 1. The calculated CI is shown on the Figure 9 for 3D and 2D video file as well. Lines of averages are plotted with bold lines and margins of CI (deviation) are plotted with dashed lines. The biggest QoE sensibility was under 8000 kbit/s bitrate for 3D video and under 6000 kbit/s bitrate for 2D content.

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 efficient transport of these contents even in unicast mode. The relationship between QoE and QoS was shown based on the gathered results for 3D stereoscopic multimedia content and for the 2D type of same content as well. Evaluation of data was carried out by the IBP Statistics software. QoS metrics like jitter and bandwidth limitation disturbance and changing of multimedia features like quantization increase and video bit-rate decrease are demonstrated by tests results. The quality of 3D presentation like depth impression is influenced by multimedia features, and dynamic, lots of movement sections in video are more sensitive to the QoS degradation.

Future work will address investigation of QoE and QoS relationship of 3D video streams in wireless environment and comparison of obtained information with up to now evaluated QoE tests results. The goal is to get enough data for mathematical modeling of functional relationship between QoE and QoS metrics in case of 3D stereoscopic video contents.

Acknowledgement

This work was supported by NKTH-OTKA grant CNK77802.

References

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

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

[3] 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

[4] Kroeker L. Kirk „Looking Beyond Stereoscopic 3D's Revival" Communications of the ACM, Volume 53 Issue 8, August 2010, pp. 14-16

[5] 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

[6] 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

[7] 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

[8] 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

[9] 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)

[10] 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)

[11] 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

[12] 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

[13] Quin Dai „A Survey of Quality of Experience" In. Ralf Lehnert (Ed.) EUNICE 2011. LNCS, vol. 6955, pp.146 – 156 Springer, Heidelberg (2011)

[14] 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)

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