Effect of Delivery Latency, Feedback Frequency and Network Load on Adaptive Multimedia Streaming

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Abstract— **As video on demand systems gain popularity, it seems likely that the desire to serve a high number of customers from limited network resources could lead to a degradation of the end-users' perceived quality. Quality-Oriented Adaptation Scheme (QOAS) balances the need for high quality with increased network utilization when streaming multimedia. QOAS requires client-side monitoring of some transmission-related parameters, grading of the end-user's quality and feedback that informs the server about the received quality. In response to this feedback, the server adjusts the streaming process in order to maximize the end-user perceived quality in the current conditions. This paper studies the effect of delivery latency and feedback frequency on quality-oriented adaptive multimedia streaming. It also shows how high end-user perceived quality is maintained in the presence of different types of background traffic while recording a significant increase in link utilization and a very low loss rate.**

Keywords-Adaptive video streaming, grading scheme, end-user perceived quality.

I. INTRODUCTION

The percentage of households with broadband connections was very low in Europe in 2001 (1.93% in Germany, France and Britain), and moderate in America (13%) [1] and parts of Asia (17% in Korea) [2]. However as predicted in [3], the broadband penetration experienced a significant increase in the last years reaching an impressive 90% in Korea, 55% in UK and 53% in US in 2007 [4]. A sustained growth in the number of broadband connections is predicted for the near future, with more than 10% annual increase in the Eastern Europe and some Asian countries [4]. At the same time the evolution towards an all-IP architecture will continue [5] allowing a wider use of already popular IP applications and low cost hardware. In such a context, service providers want to enhance their profitability by providing new revenue-producing services that offer high-quality rich content to their customers (e.g. TV over IP, Video-on-Demand - VOD) and increase their market penetration, while optimizing infrastructure utilization.

Quality-Oriented Adaptation Scheme (QOAS) [6, 7] for multimedia streaming dynamically balances the customers' need for high-quality service with the service providers' goal of increasing the number of end-users that can be simultaneously served. QOAS adaptive mechanism is based on client feedback that takes into consideration both the end-user perceived quality and the values of some transmission related parameters. QOAS reacts to feedback in real-time by adjusting the transmitted quantity of data – and hence the quality of the multimedia stream – in order to maximize the viewers' perceived quality in the current delivery conditions.

This paper studies the effect of delivery latency and feedback frequency on quality-oriented adaptive multimedia streaming in a delivery network where multimedia traffic accounts for the large majority of traffic. The paper also presents QOAS evaluation test results that show its positive performance when used for streaming multimedia via networks that also deliver other traffic of different types, rates and variation patterns.

The paper starts with a description of the architecture of the multimedia system that deploys QOAS and a brief presentation of the QOAS principle. Some related works are then mentioned before simulation and perceptual test results are presented in details. The paper ends with conclusions and future work directions.

II. QOAS ADAPTIVE MULTIMEDIA STREAMING SYSTEM ARCHITECTURE

The architecture of the QOAS-based adaptive multimedia system is presented in Figure 1. It includes multiple instances

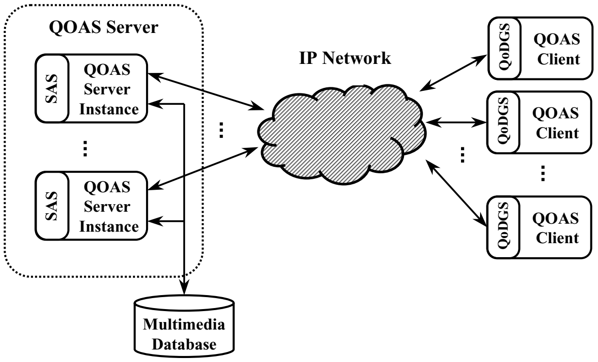

Figure 1 QOAS-based multimedia streaming system architecture

of QOAS adaptive client and server applications that bi-directionally communicate through an IP multi-service delivery network. They exchange multimedia data and control packets (including feedback).

The QOAS client and server application instances implement the proposed adaptive multimedia streaming scheme. The **QOAS Client Application** monitors some transmission-related parameters and the end-user perceived quality, allowing for its ***Quality of Delivery Grading Scheme (QoDGS)*** to compute scores that reflect the overall quality of the streaming process. The computed grades are then sent as feedback to the **QOAS Server Application** instance, whose ***Server Arbitration Scheme (SAS)*** analyses them and proposes adjustment decisions in order to try to maximize end-user perceived quality in the given client-reported conditions. The **Multimedia Database** stores the multimedia streams in the pre-recorded streaming case, and some indexing information necessary in the adaptation process.

III. RELATED WORK

Different solutions were proposed for offering certain level of Quality of Service when streaming multimedia over IP networks, including adaptive schemes [8, 9, 10].

The large majority of the recent adaptive solutions proposed for multimedia streaming is **sender-based**, giving a significant role to the server in taking the adaptive decisions. Among them, the ***Loss-Delay based Adjustment algorithm (LDA)*** [11] relies on RTCP reports to estimate both round trip delays and loss rates and estimates the bottleneck link bandwidth. The scheme controls the transmission rate using these estimates, but also bases its functionality on some parameters that have to be set by users. The ***enhanced Loss-Delay Adaptation algorithm (LDA+)*** [12] makes also use of RTCP reports to collect loss and delay statistics. The scheme uses them to adjust the transmission rate in a similar manner to TCP connections subject to equal losses and delays. ***Rate Adaptation Protocol (RAP)*** proposed in [13] uses TCP-like acknowledgement of the packets to estimate loss rates and delays. In case of no loss, the rate is additively increased function of round trip delay, whereas in case zero loss, the rate is halved as TCP does. ***Layered Quality Adaptation (LQA)*** [14] is one of the most significant schemes that make use of the properties of layered-encoding in supporting rate-controlled adaptations. It modifies the bitrate and consequently the quality of the transmitted multimedia by adding and removing a layer respectively. In [15] a ***TCP-Friendly Rate Control Protocol (TFRCP)*** is presented, based on a TCP model previously proposed in [16]. In case of losses, the rate is limited to the equivalent TCP rate computed according to the TCP model otherwise the rate is doubled. Significant issues related to TFRCP are its variability and as it updates its rate every 2 - 5 s it cannot keep up with changes in traffic that occur on a faster scale.

The **receiver-based schemes** provide mechanisms that allow for the receivers to select the service quality and/or rate such as ***Receiver-driven Layered Multicast (RLM)*** [17] and ***Receiver-driven Layered Congestion Control (RLC)*** [18]. The ***TCP Emulation At Receivers (TEAR)*** scheme, described in details in [19] is a significant **hybrid adaptive mechanism** that involves both the sender and the receiver in the adaptation process. The **transcoder-based solutions** focus on matching the available bandwidth of heterogeneous receivers through transcoding or filtering [20, 21].

These adaptive solutions base their adjustments on transmission-related information collected at the client and either sent via feedback (mainly RTCP) to the server [13, 22, 23, 24, 25] or processed locally [17], on encoding log files [26] or on direct analysis of delivery process [20, 21]. For increasing the performance of multimedia deliveries to large numbers of clients, multicasting [17, 27, 28] and cache-based solutions [29, 30] have also been proposed.

Commercial adaptive streaming solutions like Real Networks' ***SureStream*** [25] and Microsoft's ***Multimedia Multi-bitrate (MBR)*** solution [31] are proprietary and detailed technical information has never been revealed. However the available information states that they were specially designed to allow for adaptations at very low bitrates, unlike QOAS that addresses high quality, high bitrate video streams.

Although these adaptive schemes have shown good adaptation results in certain scenarios, their adjustment policies are not directly related to the quality of the streaming process as perceived by the clients such as is QOAS's.

IV. QUALITY-ORIENTED ADAPTIVE SCHEME (QOAS)

Unlike other adaptive schemes, QOAS bases its adaptation process on estimates of the end-user perceived quality made at the receiver [7]. This perceived quality is estimated in-service using the no-reference Moving Picture Quality Metric (Q) proposed in [32] that describes the joint impact of MPEG rate and data loss on video quality.

QOAS is distributed and consists of server side and client-side components. It makes use of a client-located Quality of Delivery Grading Scheme (QoDGS) and of a Server Arbitration Scheme (SAS) that co-operate in order to implement the feedback-controlled adaptation mechanism. The QOAS principle is briefly described next.

A. QOAS Principle

Multimedia data is received at the client where the QoDGS continuously monitors both some network-related parameters such as loss rate, delay and jitter and the estimated end-user perceived quality. According to their values and variations, QoDGS grades the quality of delivery (QoD) in terms of application-level quality scores (QoD_{Score}-s) that are sent to the server as feedback. These scores are analysed by the SAS that may suggest taking adaptive decisions in order to maximize the end-user perceived quality in existing delivery conditions. These decisions affect an internal state defined for the QOAS server component that was associated with the streamed multimedia clip's quality. For example the five-state quality model used during testing has the following states: excellent,

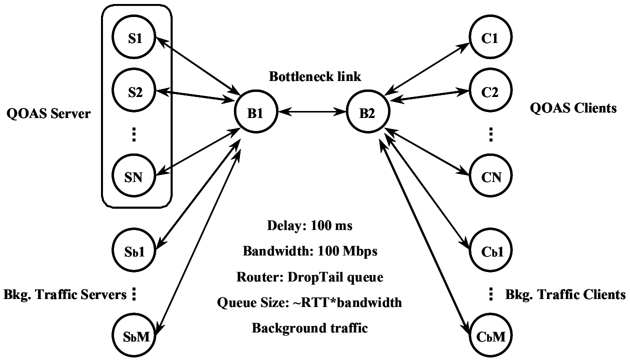

Figure 2 Simulation topology that includes a bottleneck link, a server and N clients, as well as a number of sources and receivers of background traffic

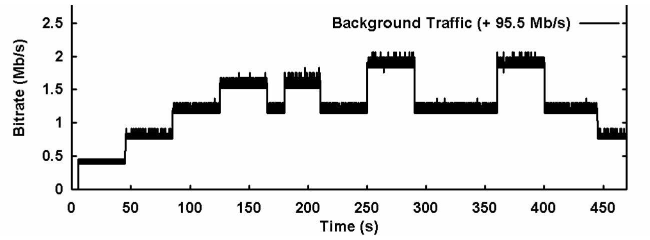

Figure 3 Multimedia-like background traffic generated on top of 95.5 Mbps CBR UDP traffic

good, average, poor and bad. Any QOAS server state modification affects the multimedia data transmission rate. When increased traffic in the network affects the client-reported quality of delivery, SAS switches to a lower quality state, which determines a reduction in the quantity of data sent, helping to improve the situation. This is performed as research has shown [33] that viewers prefer a controlled reduction in multimedia quality to the effect of random losses on the streamed multimedia data. In improved delivery conditions, the QOAS server component gradually increases the quality of the transmitted stream and in consequence the transmission rate. In the absence of loss this causes an increase in end-user perceived quality.

B. *Quality of Delivery Grading Scheme (QoDGS)*

QoDGS maps some transmission related parameters values and variations and estimates of end-user perceived quality into application-level scores that describe the quality of delivery. It monitors parameters such as delay, jitter and loss rate, computes estimates of end-user perceived quality using Q and analyses their short-term and long-term variations. Short-term monitoring is important for learning quickly about transient effects such as sudden traffic changes and for fast reacting to them. The long-term variations are monitored in order to track slow changes in the overall delivery environment such as new users in the system which need a reaction to. These short-term and long-term periods are considered, an order and two orders of magnitude greater than the feedback-reporting interval.

In the first of the QoDGS's three stages, instantaneous values of the monitored parameters are saved in different length sliding windows and their short-term and long-term variations are assessed. At the same time, session-specific lower and higher limits are maintained for each parameter, allowing for corresponding partial scores to be computed in comparison with them. In the second stage, the relative importance of all the monitored parameters and the estimated end-user perceived quality is considered (by weighting their contributions) and short-term and long-term quality of delivery grades are computed. In the third stage, the overall client score (QoD_{Score}) is computed.

TABLE I. STATISTICS RELATED TO THE DIFFERENT QUALITY ENCODED VERSIONS OF THE *DIEHARD1* CLIP

State (0-4)	Avg. Encoding Rate (Mbps)	Peak/Mean Ratio
0	2.00	7.48
1	2.50	7.43
2	3.00	6.31
3	3.50	5.65
4	4.00	4.06

Extensive tests performed made sure that the QoDGS helps obtain the best results in terms of adaptiveness, responsiveness to traffic variations, stability, link utilization and end-user perceived quality in local broadband IP-networks [7].

C. *Server Arbitration Scheme (SAS)*

SAS takes adaptive decisions based on the values of a number of recent feedback reports, in order to minimise the effect of noise in the QoD_{Score}-s. This arbitration process is ***asymmetric*** requiring fewer feedback reports to trigger a decrease in quality than for a quality increase. This ensures a fast reaction during bad delivery conditions, helping to eliminate their cause and allow for the network conditions to improve before any quality upgrade. These adaptive decisions are such performed that maintain system stability by minimising the number of quality variations. The late arrival of a number of feedback messages is considered as an indication of network congestion and triggers quality degradations. This permits the functionality of the streaming scheme even if the feedback is not available. More details about SAS are presented in [7].

V. EXPERIMENTAL TESTING

A Network Simulator 2 (NS-2) [34] model that deploys QOAS is used to test the behavior of QOAS against different types of background traffic as the main source for delivery problems. It is also used to assess the effect of latency and feedback frequency.

A. *Simulation Topology*

The "Dumbbell" topology presented in Figure 2 was used. It assumes a single shared bottleneck link used for all the simulations. The sources of traffic are located on one side of the bottleneck link, whereas the receivers are on the other side.

The QOAS Server is modeled as a number of QOAS server application instances that communicate with the same number of QOAS client application instances. The other sources

TABLE II. TEST RESULTS WITH DIFFERENT TYPES OF BACKGROUND TRAFFIC

Background				**QOAS vs. Ideal Adaptive**					
Type	**Shape**	**No x Rate Mbps**	**Other CBR Mbps**	**QOAS Rate Mbps**	**Ideal Rate Mbps**	**QOAS Quality 1-5**	**Ideal Quality 1-5**	**QOAS Loss %**	**QOAS Utilisation %**
CBR	Periodic	1 x 0.5	96.0	3.76	3.84	4.54	4.55	0.0	99.87
CBR	Periodic	1 x 0.7	96.0	3.33	3.55	4.46	4.50	0.0	99.72
CBR	Staircase ↑	4 x 0.4	95.5	3.59	3.62	4.51	4.52	0.0	99.90
CBR	Staircase ↑	4 x 0.6	95.5	3.03	3.09	4.31	4.39	0.09	99.95
CBR	Staircase ↓	4 x 0.4	95.5	3.57	3.70	4.50	4.53	0.0	99.77
CBR	Staircase ↓	4 x 0.6	95.5	3.02	3.30	4.31	4.45	0.006	99.63
TCP	FTP	50 x 0.44	75.0	3.04	3.14	4.39	4.42	0.0	98.42
TCP	FTP	54 x 0.42	75.0	2.73	2.78	4.29	4.31	0.04	98.43
TCP	WWW	40 x 0.012	95.5	3.80	4.02	4.54	4.58	0.0	99.69
TCP	WWW	50 x 0.018	95.5	3.50	3.59	4.49	4.51	0.0	99.80
VBR	0.001s on/0.1s off	1 x 1.0	95.5	3.65	3.66	4.52	4.52	0.0	99.94
VBR	0.01s on/ 0.1s off	1 x 1.0	95.5	3.65	3.66	4.52	4.52	0.0	99.94
VBR	0.1s on/ 0.1s off	1 x 1.0	95.5	3.60	3.64	4.51	4.52	0.0	99.93

produce the background traffic to be routed towards corresponding receivers. Apart from the bottleneck link, the other links are over-provisioned such as the only drops and significant delays are caused by congestion that occurs at the bottleneck link (bandwidth 100 Mbps and link delay 0.05 s). The buffering at the bottleneck link uses a drop-tail queue of length proportional with the product between the round trip time and the bandwidth of the bottleneck link. During simulations this bandwidth was set to 100 Mbps and the bottleneck link's delay was set to 0.1 s.

B. *Performance Assessment*

In order to assess the performance of the proposed adaptive scheme, its behavior is related to one of an ideal adaptive mechanism that would perform in the same conditions. This ideal adaptive scheme (IDL) is defined in terms of loss, perceived quality and bottleneck link utilization. IDL should achieve 0% loss and reach 100% bottleneck link utilization, while maximizing the end-user perceived quality by using all the available bandwidth (not used by other traffic) in given transmission conditions. The end-perceived quality is determined by using the no-reference Moving Picture Quality Metric (Q) [32].

C. *Scenarios Simulation Model and Multimedia Streams*

Simulation tests were performed using NS-2 and a model that implements QOAS. Five-quality states were defined for the server adaptation space and consequently multimedia sequences were repeatedly MPEG-2 encoded at 2.0 Mbps, 2.5 Mbps, 3.0 Mbps, 3.5 Mbps and 4.0 Mbps respectively, using the same frame rate (25 frames/s) and the same IBBP frame pattern (9 frames/GOP). The video traces were collected and used during simulation. For each sequence, each trace is associated to a server state that corresponds to its quality. Tests were performed using multimedia clips with different motion content and the results were similar. For exemplification this paper presents testing results involving a multimedia sequence with very complex motion content - *diehard1*. Statistic information related to this sequence is shown in Table I.

D. *Performance Effect of Background Traffic Type, Rate and Variation Pattern*

Different types of background traffic commonly expected in IP networks and with different variation patterns are generated using NS-2 built in models. CBR, TCP and VBR traffic are three main classes of traffic taken into account on top of CBR traffic of at least 95.5 Mbps. This traffic simulates a well-multiplexed real-life traffic that determines loaded delivery conditions and causes QOAS adaptive reactions.

The effect of different shaped CBR traffic on the QOAS was tested such as *periodic*, with different periodicity (e.g. 40 s on - 80 s off in these tests), *staircase up* and respectively *staircase down*, with different step sizes (e.g. 4 stairs of 0.4 Mbps and 0.6 Mbps here). The latter consists of a number of CBR streams that start and end at different moments in time situated 40 s apart and tests the QOAS asymmetric behavior while adapting upwards and respectively downwards.

Different types of FTP traffic were considered such as FTP flows (i.e. long-lived TCP), and WWW (i.e. short lived TCP) and in different number.

Table II presents testing results which show how QOAS had very good behavior both in terms of various quality of service parameters such as loss and throughput and in terms of estimated end-user perceived quality. It is significant to note that these results are very close to those an ideal adaptive scheme could achieve in the same conditions.

E. *Performance Effect of Feedback Frequency*

The following set of tests study how the frequency of QOAS feedback influences the consequent end-user perceived quality of the streamed multimedia in local broadband delivery networks. Since QOAS-based systems target this type of

TABLE III. EFFECT OF FEEDBACK FREQUENCY ON QOAS PERFORMANCE WHEN STREAMING *DIEHARD1* AGAINST MULTIMEDIA-LIKE TRAFFIC

Feedback Interval (s)	**Avg. Tx. Rate (Mbps)**	**Avg. Loss Rate (%)**	**Avg. Perceived Qual. (1-5)**	**Avg. Link Utilis. (%)**
0.01	3.22	0.24	4.33	99.97
0.05	3.21	0.07	4.39	99.99
0.1	3.12	0.02	4.38	99.93
0.5	3.20	0.05	4.37	99.99
1.0	2.99	0.13	4.19	99.79
2.0	2.98	0.09	4.28	99.79
5.0	2.86	0.06	4.26	99.70
10.0	3.26	1.32	3.38	99.98

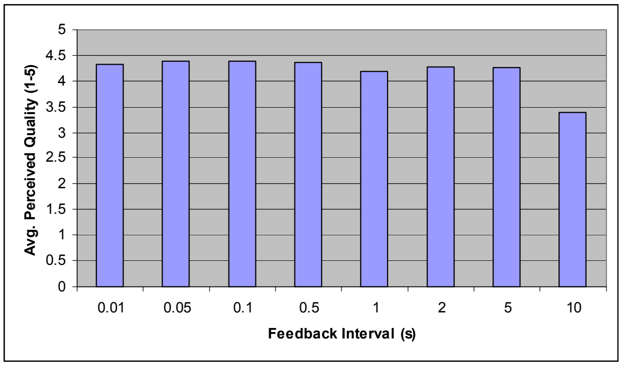

Figure 4 Average QOAS multimedia perceived quality dependency on feedback interval

TABLE IV. EFFECT OF DELIVERY LATENCY ON QOAS PERFORMANCE WHEN STREAMING *DIEHARD1* AGAINST MULTIMEDIA-LIKE TRAFFIC

Delivery Latency (s)	**Avg. Rate (Mbps)**	**Avg. Loss Rate (%)**	**Avg. Perceived Qual. (1-5)**	**Avg. Link Utilis. (%)**
0.01	3.17	0.031	4.391	99.94
0.05	3.07	0.026	4.353	99.84
0.1	3.12	0.015	4.384	99.93
0.2	3.11	0.280	4.279	99.89
0.5	3.16	0.777	4.086	99.90

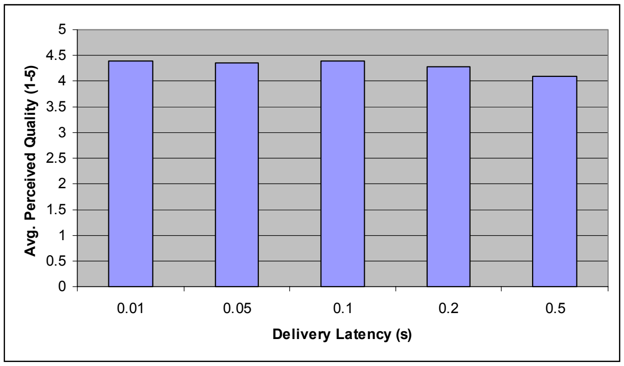

Figure 5 Average QOAS multimedia perceived quality dependency on delivery latency

networks in which the majority of traffic consists of multimedia streams, the simulations are performed with multimedia-like background traffic. Multimedia traffic is modeled through CBR traffic since the statistical multiplexing effect due to the bottleneck link buffering tends to flatten the burstiness usually associated with the multimedia streams.

A highly variable multimedia-like traffic shown in Figure 3 is transmitted across the delivery network on top of 95.5 Mbps of CBR background traffic, which creates highly loaded network conditions. This traffic simulates all possible effects of user interactions to multimedia streams such as play, pause, re-play and stop. It takes into account the effect of multiple consecutive play commands that increase the traffic in a staircase up manner, consecutive pause-play interactions and consecutive stop requests that decrease the traffic in a staircase-down fashion. This traffic was considered representative for this case since interactive controlled multimedia should account for the majority of the traffic carried by this network.

The tests involve a five-quality state QOAS server streaming multimedia sequences with different motion content over the "Dumbbell" topology to a QOAS client. The time between two consecutive feedback reports sent by the client to the server is varied from 0.01 s to 10 s. The QOAS performance-related results when streaming *diehard1* - a sequence with very high motion content (see Table I) are presented in Table III. They are expressed in terms of average transmission rate, average loss rate, average perceived quality and average link utilization. In particular Figure 4 illustrates how feedback frequency affects QOAS multimedia streaming quality.

It is significant to note that the end-user perceived quality slightly decreases with the increase in the inter-feedback transmission time as expected. At low feedback frequencies the QOAS server may not receive information about changes in the delivery conditions fast enough to react adaptively to them. Therefore it either is unable to avoid consequent losses or it does not efficiently use the available bandwidth. As direct consequence, in both cases the end-user perceived quality decreases. Table III shows how for an inter-feedback transmission time of 10 s the average end-user perceived quality has decreased to "fair" subjective level (3.38) from above "good" (4.39) when the feedback interval was set to 0.05 s.

Although it seems that feedback has to be sent as often as possible, this has two major disadvantages. Firstly feedback takes bandwidth that is both expensive and limited. Secondly processing feedback takes CPU time at both client machine and most importantly at the server. The server can be easily overwhelmed by a very high number of client feedback messages. In consequence the inter-feedback transmission time has to balance the need for high end-user perceived quality with efficient usage of shared resources. Relative to the latter, RTCP recommendation that feedback has to account for less than 5% of bandwidth is taken into account.

The bandwidth used for feedback ($BW_{feedback}$) by a number of N QOAS streaming processes is shown in equation (1), where $\text{Time}_{\text{feedback}}$ is the inter-feedback transmission time and $\text{Size}_{\text{feedback}}$ is the feedback packet size. For standard values for the header sizes (i.e. 20 bytes – IP, 8 bytes – UDP and 8 bytes – RTCP) and for 4 bytes QOAS payload, $\text{Size}_{\text{feedback}}$ is 40 bytes.

$$BW_{feedback} = \frac{N * Size_{feedback}}{Time_{feedback}} \qquad (1)$$

Taking into consideration that QOAS was designed for delivering multimedia in loaded local broadband IP networks [6], for a one gigabit Ethernet on which 320 customers are served with "good" perceived quality as in [34], the total bandwidth used by feedback when employing a very low inter-feedback transmission time of 0.01 s is: 320*4,000=1,280,000 bytes/s. This value, in fact 9.77 Mbps, is less than 1 % of the total available bandwidth and conforms to the RTCP recommendation.

At the same time the feedback messages number ($\text{No}_{\text{feedback}}$) that the QOAS server application must deal with in the presence of a high number of simultaneous customers (N) becomes very high and reaches $\text{N/Time}_{\text{feedback}}$ =32,000 every second, loading much the server without a significant gain in the end-user perceived quality.

By using a 0.1 s interval between feedbacks both the load on the QOAS server and the bandwidth required to send feedback are reduced. This value allows for good adaptation based on fast and accurate information regarding the delivery conditions whereas efficiently using shared resources. In these conditions QOAS achieves excellent performance in terms of end-user perceived quality, loss rate and link utilization.

F. *Performance Effect of Delivery Latency*

The tests described in this section determine how the variation in the latency of the delivery network affects the performance QOAS multimedia streaming and especially the end-user perceived quality.

The tests involve the "Dumbbell" topology presented in Figure 2 over which, *diehard1* (clip properties are presented Table I) is streamed using QOAS model. NS-2 built-in models are used to generate background traffic with the variation presented in Figure 3 that simulates real-life multimedia-like traffic. This traffic is generated on top of a 95.5 Mbps CBR traffic that simulates a well-multiplexed natural traffic and determines loaded delivery conditions.

The bottleneck link delay is varied from 0.01 s to 0.5 s while maintaining constant the inter-feedback transmission interval of 0.1 s. The consequent QOAS performance related results, expressed in terms of average transmission rate, loss rate, end-user perceived quality and link utilization are shown in Table IV. An illustration of delivery latency effect on quality of multimedia streaming using QOAS is presented in Figure 5.

The test results show how the end-user perceived quality when using QOAS decreases with the increase in the delivery link latency. This conclusion may seem natural since the longer the time takes for the feedback to be received, processed by the server and the eventual consequent adjustments to be noticed at the receiver, the greater the chance these adjustments not to match the new existing delivery conditions. For long delivery latencies the QOAS server may not receive feedback information about changes in the delivery conditions fast enough to react to them. Consequently either loss will occur or the available bandwidth will not be fully used, both causing end-user perceived quality to be affected. For example for a link delay of 0.5 s, the average end-user perceived quality has dropped to "good" subjective level (4.09) from much above that (4.39) achieved when the delivery latency was 0.01 s. For latencies higher than 0.5 s the average perceived quality dropped below "good" level considered here the least acceptable for video on demand services.

In this context it seems that feedback has to arrive at the server as fast as possible. However the link latencies depend very much of the architecture of the local broadband IP networks and in general the shortest the link delay, the more expensive the solution is. In consequence a compromise must be found for the link delay, balancing the need for high quality with the infrastructure-related costs of the solution.

VI. CONCLUSIONS AND FURTHER WORK

The paper analyzes the effect of delivery latency and feedback frequency on quality-oriented adaptive multimedia streaming in a delivery network where multimedia traffic accounts for the large majority of traffic. The paper also presents test results that show positive performance gains when QOAS is used for streaming multimedia via networks that also deliver other traffic with different types, rates and variation patterns.

Simulation tests that involve an adaptive multimedia streaming model show that by using QOAS very good performance in terms of end-user quality, loss rate and infrastructure utilization was achieved. They indicate that QOAS works very well in various delivery conditions, with different types of background traffic such as UDP (CBR and VBR) and TCP (long-lived - FTP and short-lived - WWW), of various rates and with different variation patterns. Therefore QOAS finds its best applicability in residential broadband delivery networks [5] and especially as a solution for distributing video on demand [36] and/or other multimedia based interactive entertainment to customers.

Further work involves TCP-friendliness assessment and QOAS testing when streaming multimedia over wireless networks.

REFERENCES

[1] Pastore, M., “Broadband Lacks a European Audience”, CyberAtlas, Feb. 5, 2002, http://cyberatlas.internet.com

[2] “Korea leads broadband Internet service market”, KoreaNow, Nov. 2002, http://kn.koreaherald.co.kr

[3] KMI Corp., “FTTH To Reach 2.65 Million Homes By 2006”, Press Release, 2001, http://www.kmicorp.com/press/011015.htm

[4] Wray, R., “Broadband spreads across globe”, The Guardian, UK, June 13th, 2007, http://business.guardian.co.uk/story/0,,2102304,00.html

[5] Dravida, S., Gupta, D., Nanda, S., Rege, K., Strombosky, J., Tandon, M., “Broadband Access over Cable for Next-Generation Services: A Distributed Switch Architecture”, IEEE Comm. Magazine, vol. 40, no. 8, August 2002, pp. 116–124

[6] Muntean, G.-M., Perry, P., Murphy, L., “Objective and Subjective Evaluation of QOAS Video Streaming over Broadband Networks”, IEEE eTransactions on Network and Service Management, vol. 2, no. 1, November 2005, pp. 19-28

[7] Muntean, G.-M., “Efficient Delivery of Multimedia Streams over Broadband Networks using QOAS”, IEEE Trans. on Broadcasting, vol. 52, no. 2, June 2006, pp. pp. 230-235

[8] Aurrecoechea, C., Campbell, A. T., Hauw, L., "A Survey of QoS Architectures", ACM Multimedia Systems Journal, Special Issue on QoS Architecture, Vol. 6, No. 3, 1998, pp. 138-151

[9] Wu, D., Hou, Y. T., Zhu, W., Zhang, Y.-Q.,Peha, J. M., “Streaming Video over the Internet: Approaches and Directions”, IEEE Trans. Circ. and Sys. Video Tech., vol. 11, no. 3, 2001, pp. 282–300

[10] Wang, X., Schulzrinne, H., "Comparison of Adaptive Internet Multimedia Applications", IEICE Trans. on Comms., Vol. E82 - B , No. 6, June 1999, pp. 806 – 818

[11] Sisalem, D., Schulzrinne, H., “The Loss-Delay Based Adjustment Algorithm: A TCP-Friendly Adaptation Scheme”, Proc. ACM NOSSDAV, 1998

[12] Sisalem, D., Wolisz, A., “LDA+ TCP-Friendly Adaptation: A Measurement and Comparison Study”, ACM NOSSDAV, 2000

[13] Rejaie R., Handley, M., Estrin, D., “RAP: An End-to-end Rate-based Congestion Control Mechanism for Realtime Streams in the Internet”, Proc. IEEE INFOCOM, 1999

[14] Rejaie, R., Handley, M., Estrin, D., "Layered Quality Adaptation for Internet Video Streaming", IEEE Journal Sel. Areas Comms., Special Issue on Internet QoS, vol. 18, no. 12, Dec. 2000, pp. 2530-2543

[15] Padhye, J., Kurose, J., Towsley, D., Koodli, R., “A Model Based TCP Friendly Rate Control Protocol”, ACM NOSSDAV, 1999

[16] Padhye, J., Firoiu, V., Towsley, D., Kurose, J., “Modelling TCP Throughput: A Simple Model and Its Empirical Validation”, Proc. ACM SIGCOMM, Vancouver, Canada, October 1998

[17] McCanne, S., Jacobson, V., Vetterli, M., "Receiver-Driven Layered Multicast", Proc. ACM SIGCOMM, Stanford, California, USA, August 1996, pp. 117-130

[18] Vicisano, L., Crowcroft, J., Rizzo, L., “TCP-like Congestion Control for Layered Multicast Data Transfer”, Proc. IEEE INFOCOM, vol. 3, San Francisco, CA, USA, March 1998, pp. 996-1003

[19] Rhee, I., Ozdemir, V., Yi, Y., “TEAR: TCP Emulation at Receivers Flow Control for Multimedia Streaming”, Technical Report, CS Department, NCSU, April 2000

[20] Wang, L., Luthra, A., Eifrig, B., “Rate Control for MPEG Transcoders”, IEEE Trans. On Circuits and Systems for Video Technology, vol. 11, no. 2, Feb. 2001 pp. 222–234

[21] Yeadon, N., Garcia, F., Hutchison, D., Shepherd, D., "Filters: QoS Support Mechanisms for Multipeer Communications", IEEE J. on Selected Areas in Comp., vol. 14, no. 7, Sept. 1996, pp 1245-1262

[22] Bolot, J. C., Turletti, T., "Adaptive Error Control for Packet Video in the Internet", Proc. of ICIP, Lausanne, Switzerland, Sept. 1996

[23] Sisalem, D., "End-To-End Quality of Service Control Using Adaptive Applications", Proc. 5th IFIP International Workshop on Quality of Services, New York, USA, 1997, pp. 381-392

[24] Kanakia, H., Mishra, P., Reibman, A., "An Adaptive Congestion Control Scheme For Real-time Packet Video Transport", Proc. ACM SIGCOMM, San Francisco, USA, Sept. 1993, pp. 20-31

[25] RealNetworks, SureStream, http://www.realnetworks.com

[26] Böröczky, L., Ngai, A. Y., Westermann, E. F., "Statistical Multiplexing Using MPEG-2 Video Encoders", IBM Journal Research and Development, vol. 43, no. 4, 1999

[27] Ramesh, S., Rhee, I., Guo, K., "Multicast with Cache (MCache): An Adaptive Zero-Delay Video-on-Demand Service", IEEE Trans. On Circuits and Systems for Video Tech., vol. 11, no. 3, March 2001

[28] Liu, J., Li, B., Zhang, Y.-Q., “Adaptive Video Multicast over the Internet”, IEEE Multimedia, Vol. 10, No. 1, Jan 2003, pp. 22-33

[29] Rejaie, R., Yu, H., Handley, M., Estrin, D., “Multimedia Proxy Caching Mechanism for Quality Adaptive Streaming Applications in the Internet”, IEEE INFOCOM, 2000, pp. 980-989

[30] Verscheure, O., Venkatramani, C., Frossard, P., Amini, L., “Joint Server Scheduling and Proxy Caching for Video Delivery”, ACM Computer Communications Journal, no. 25, 2002, pp. 413-423

[31] Microsoft, Windows Media, MBR, http://www.microsoft.com

[32] Verscheure, O., Frossard, P., Hamdi, M., “User-Oriented QoS Analysis in MPEG-2 Video Delivery”, Journal of Real-Time Imaging, vol. 5, no. 5, October 1999, pp. 305-314

[33] Ghinea, G., Thomas, J. P., “QoS Impact on User Perception and Understanding of Multimedia Video Clips”, Proc. of ACM Multimedia, Bristol, UK, 1998

[34] Network Simulator-2, http://www.isi.edu/nsnam/ns

[35] ITU-T Recommendation P.910, “Subjective Video Quality Assessment Methods for Multimedia Applications”, Sept. 1999

[36] Wong, E. W. M., Chan, S. C. H., “Performance Modeling of Video-on-Demand Systems in Broadband Networks”, IEEE Trans. Circ. Sys. for Video Tech., vol. 11, no. 7, July 2001, pp. 848–859