Quality Level Control for Multi-user Sessions in Future Generation Networks

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***Abstract* – Real-time multimedia sessions are now present in our daily live experience, and will be among the most important applications in future generation networks. The distribution of those sessions, towards fixed and mobile users, with *Quality of Experience* (QoE) assurance is important to attract and keep customers, while increasing the profits of providers. This paper proposes the *Quality Level Control for Multi-user Session* (QUALITIS) approach to assure the quality level of sessions shared by multiple users (multi-users) in future generation networks. QUALITIS aims to keep sessions with an acceptable quality level and to avoid session blocking. The QUALITIS control is achieved by coordinating *Quality of Service* (QoS) mapping, QoS adaptation, resource allocation and mobility mechanisms. Performance evaluation was carried out based on simulation experiments and verified the QUALITIS impact on the user's expectation and on the performance of the network.**

***Index Terms:* QoS; QoE, Multimedia, Mobility**

I. INTRODUCTION

The efficient management and distribution of real-time group communication sessions, such as IPTV, video streaming and push media, in future generation networks is still a challenging research goal. From the network point of view, this challenge is mainly due to the use of different QoS models and the presence of (wired and wireless) links with distinct and varying capacities. From the user (mobile or fixed) point of view, the challenge is to assure their agnostic view of the underlying QoS infrastructure, and to allow them to access multimedia sessions anytime and anywhere with QoE assurance (e.g., a video with acceptable resolution, noise and luminance) [1].

Multi-user sessions can be classified as non-scalable and scalable. The latter is composed of a set of flows with well-defined priorities, QoS and QoE requirements. Such flows can be supported by common CODECs (e.g., H.264, MPEG-2 and MPEG-4). The quality level of a session is defined based on QoS metrics, such as bit rate, packet loss and packet delay, as well as on QoE metrics, such as *Video Quality Metric* (VQM) [2]. QoS measurements can be used to estimate the impact on the session perceived quality in a networking system, but do not reflect the session quality from the user point of view. On the other hand, QoE measurements show the session impact on the user's expectation during its distribution in a network.

The QoE support for multi-user sessions in user-centric systems is complex and depends mainly on end-to-end network engineering operations, because the session content is transported along heterogeneous networks with different QoS models, service classes, as well as links with distinct capacities. Therefore, in order to assure the suitable wireless and wired classes for the session along the end-to-end path, a solution is required to map the session requirements into service classes inside or between networks, independently of underlying QoS models. Additionally, due to the existence of links and service classes with different and oscillating capacities, sessions must be adapted to the current network conditions. Such adaptation must take into account the priority of each flow of a multi-user session, reducing the impact of oscillatory network conditions on the overall session quality. The adaptation scheme must be also independent from application CODECs and multimedia content in order to increase the system flexibility. In the same line of thought, mobile users must be unaware of network conditions. In the presence of network congestion the combination of mapping and adaptation network techniques allows dynamic session (re)mapping operations, minimizes session blocking and reduces the impact on the quality level perceived by mobile users.

Our previous work [3] presented examples and benefits of QoS mapping and adaptation mechanisms in controlling the quality level of ongoing sessions. The analysis of such mechanisms was done by measuring network-based QoS parameters, such as packet loss and one-way delay, in a QoS-aware mobile system. However, although QoS metrics can be used to estimate the impact of different QoS models and link capacities on the session quality, they are insufficient to quantify the impact of the session mapping and adaptation operations on the quality perceived by users. Hence, a good understand of the impact of QoS mapping and adaptation schemes on the session quality level regarding QoE metrics is still missing.

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This paper presents the QUALITIS approach that extends our previous work by evaluating a combination of QoS mapping, QoS adaptation, mobility and resource allocation mechanisms according to the users' expectation in a simulation environment. The capability of the QUALITIS mechanism to support a good user's perceived quality during congestion periods is evaluated in terms of QoE metrics. The used QoE metrics include *Peak Signal-to-Noise Ratio* (PSNR), VQM, *Structural Similarity Index* (SSIM) and *Mean Option Score* (MOS) of a real video.

The remainder of this paper is organized as follows. Section II introduces related work. An overview of the QUALITIS is shown in Section III. Section IV presents the QUALITIS evaluation. Conclusions and future work are summarized in Section IV.

II. RELATED WORK

Regarding QoS mapping, a guideline was developed within IETF for IP QoS mapping in *Differentiated Services* (DiffServ) networks [4]. However, this approach assumes that all networks are configured with the same QoS model, service classes and performance metrics. Taking into account that networks may have different QoS models, there are mapping proposals to be used between DiffServ, or *Integrated Service* (IntServ), to IEEE 802.16 [5], and between DiffServ and IEEE 802.11e [6].

Besides its applicability between different types of networks, it is also desirable that QoS mapping mechanisms consider characteristic of applications. In this line of thought, Fan *et al* [7] propose a CODEC-based mapping approach combining DiffServ and MPEG-4 video control. In this approach MPEG4 frames are mapped into DiffServ classes according to the importance of each frame (*I*, *P* and *B*, where *I* is the most important frame). This approach protects the most important frames, reducing the impact that congestion periods have on the quality level of the session. However, the proposed QoE-based solution can only be used with MPEG-4 and DiffServ schemes.

In what concerns the selection of the most suitable network class, Rajan *et al* [8] propose a QoS mapping scheme that uses four DiffServ classes with different priorities. However, this scheme requires a manual selection of the DiffServ class by the user. Moreover, the resources in the selected class are not enough to satisfy the bandwidth required for the session, the session is rejected or remapped into the best effort class. This approach presents two major drawbacks: i) it requires manual selection of network classes, done by "expert" users; ii) does not recover the session full quality when resources assigned to the preferred class become available again.

Other types of mapping schemes require the use of proprietary modules in the user's equipment. Examples of such approaches are the ones negotiating the quality level of single-user sessions [9], or the use of a centralized QoS mapping in networks with different QoS models [10]. Besides requiring the use of proprietary modules in end-hosts, a single-user scheme is not suitable for multi-user environments, because the quality level of a session cannot be negotiated separately by each user, since a multi-user tree is a shared resource. Additionally, the use of extra modules in end-hosts and the use of centralized control schemes reduce the system flexibility and scalability, respectively.

Besides the mapping of session requirements to network capabilities, there is also the need to adjust the session quality level to oscillating network conditions. In DiffServ networks, session adaptation can be done by discarding packets according to the importance of video frames [11]. In congestion periods, packets from less important frames are dropped first. This type of QoS adaptation mechanism is not suitable for future multimedia systems, because its applicability depends on a multimedia CODEC and on a specific QoS model. Other mechanisms adapt the session rate to current networks condition based on receiver or transcoder approaches. Receiver-based solutions require the use of modules in the end-host to join/leave flows of multicast sessions [12]. On the other hand, transcoder-based proposals adapt the content, by re-coding it to the available bandwidth [13]. These solutions require a CODEC-aware system in several points of different networks, and lead to an extra computational effort in network elements, in order to (re)coding multimedia sessions.

From the related work analysis it is evident that most mapping and adaptation proposals were developed to be used in networks with specific QoS models, CODECs or need the implementation of proprietary modules in mobile devices. Other proposals do not assure the session full quality level when the network resources in the preferred class become available again. To overcome the identified limitations and to control the quality level of sessions for fixed and mobile users in future generation (heterogeneous) networks, the QUALITIS solution is proposed.

III. QUALITY LEVEL CONTROL FOR MULTI-USER SESSIONS

This section describes QUALITIS. QUALITIS controls multi-user sessions along heterogeneous wired and wireless networks, by coordinating QoS mapping and QoS adaptation mechanisms together with resource allocation and mobility mechanisms. The QUALITIS control is reflected on the session quality perceived by users (QoE). With QUALITIS, users have QoE assurance in the use of multi-user sessions, while being unaware of network classes and their available bandwidth. In addition, with QUALITIS, operators keep network internals opaque (hiding the details of the QoS infrastructure) and provide QoS/QoE control for sessions independently of the QoS models and link capacities used by their neighbor networks.

QUALITIS is a session level control scheme that uses a signaling protocol, called QUALITIS-P, to coordinate dynamic mapping and adaptation mechanisms. The

QUALITIS control aims to support the distribution of multi-user sessions with QoS/QoE assurance over heterogeneous networks. In order to allow the session delivery for fixed and mobile users with resource reservation, distribution tree maintenance and admission control, QUALITIS implements interfaces. The QUALITIS functionalities are implemented in edge network agents to increase the system scalability. Fig. 1 shows the QUALITIS components and its open interfaces with network and mobility control function schemes.

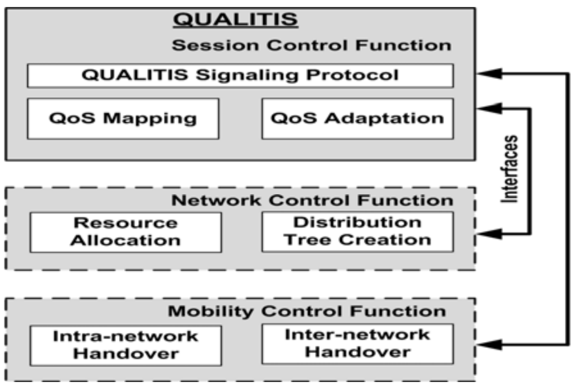

Figure 1. QUALITIS components and its interaction with resources and mobility controllers

Due to the increasing heterogeneity of access networks, the QUALITIS approach is based on the separation of session identifier and network locator as proposed in the IETF *Next Steps in Signaling* (NSIS) framework. Each session is described by a *Session Object* (SOBJ) and is identified by a global session identifier. Each session can be composed by a set of flows (scalable sessions). The QoS parameters of each flow are described in the *NSIS QoS specification* (QSPEC) [14]. The QSPEC object includes the priority, bit rate, tolerance to loss, delay and jitter of each flow. Besides the QoS information collected in the *SOBJ*, and exchanged between its agents, QUALITIS collects from the resource allocation mechanism information regarding the network classes, including the available bandwidth.

A. Interfaces

An interface with *Session Initiation Protocol* (SIP) allows fixed or mobile users to access a multi-user session. Based on this interface, applications can join and leave sessions by composing a SIP message with a *SOBJ* included in the *Session Description Protocol* (SDP). This message is received by a SIP-proxy placed in the selected access network that forwards the message to a QUALITIS agent placed in selected access router. This redirection is done based on the *SIP Location Server*. The reception of a SIP message allows the QUALITIS agent to setup the session QoS/QoE control.

An interface with a resource allocation controller allows the QUALITIS QoS mapping mechanism to query information about wired or wireless network classes and their available bandwidth. The same interface allows QUALITIS to inform the resource allocation controller about the selected network class and the bandwidth required for each flow of the multi-user session. According to the QUALITIS request, the resource allocation controller should perform admission control and resource reservation over a selected intra/inter-network path. In case of congestions, and as a consequence of a QoS adaptation, this interface is used by QUALITIS to inform the resource controller about flows that were released. An example of a resource allocation controller that can be used with QUALITIS is proposed by Neto *et al* [15].

An interface with a mobility controller allows QoS support for ongoing sessions. For multi-user sessions, *Mobile IP* (MIP)-alike schemes, such as MIPv4, MIPv6 and *Fast MIP* (FMIP)), are examples of handover solutions to be used inside and between networks. Based on this interface, QUALITIS allows the setup of ongoing sessions with QoE control on a new path. This is done after receiving a handover notification from the mobility controller with information about the IP address of the access-router to which the user is moving to. QUALITIS provides QoS/QoE control in mobile IP scenarios as reported in RFC 3583.

B. Signaling Protocol

The *QUALITIS Protocol* (QUALITIS-P) uses a soft-state approach to maintain per-session and per-flow state in each edge agent along the session path (including the *QSPEC* of each flow, which is necessary in re-routing and handover events). QUALITIS-P operates in a receiver-driven and source-initiated mode. Receiver-driven since it is triggered at the receivers' access-router. Source-initiated since the QoS configuration of QUALITIS agents starts at the agent nearest to the source, or at the first agent along the path towards the source that contains the requested session. When QUALITIS is triggered by MIP (or alike) schemes, only source-initiated functions are done to control the quality level of ongoing sessions from the *Home Agent* (HA) to the moving receivers.

C. QoS Mapping Mechanism

The mapping mechanism maps the session requirements into available service classes. It compares, one by one, the QoS parameters of each flow of the session (described in the *QSPEC*) and the list of available service classes, collected from the resource allocation controller. Then, it chooses the most suitable class based on three methods: *perfect*, *sub-perfect* and *hybrid matching*. After the class selection process, the resource controller is triggered to reserve resources for each flow in the selected service class.

The perfect match is the preferential method and assures that each flow of a session is mapped to a class of service that supports the same QoS requirements as desired in the *QSPEC*. When the preferred service class does not have enough bandwidth to assure the minimum packet loss for the session, the session is not blocked but adapted. In this case, the QoS adaptation process may decide to try a sub-perfect or a hybrid mapping.

The sub-perfect match maps all flows of a session to a service class that supports QoS parameters different from the ones described in the *QSPEC*. The mapping of all flows into another network service aims to avoid session blocking in the most suitable class and packet re-ordering. It can be used when the preferred network class in congested, while assuring the session full rate and keeping the session with an acceptable QoE (when packet delay is not crucial).

The hybrid match assures the allocation of, at least, the high priority flows of a session into the preferred class. The remainder flows are mapped to a less significant class. It can be used when packet re-ordering is not crucial.

D. QoS Adaptation Mechanism

The adaptation mechanism is triggered to adapt the quality level of multi-user sessions to current network conditions, when the available bandwidth of the preferred class cannot assure the QoS committed to some flows of a session. The adaptation process can be done by using two methods: *dropping or adding* flows, taking the flow priority into account. Dropped flows are classified by QUALITIS as sleeping. Sleeping flows are awaked when the session full rate can be supported again. The second method is the *re-mapping* adaptation, which requests the mapping of some or all flows of a session to another class (invoking the sub-perfect or hybrid mapping methods).

E. Interaction between QUALITS Components

The overall operation of QUALITIS can be briefly described as follows: the *SOBJ* created by the sources are announced to the receivers by an off-line or on-line scheme. Receivers use SIP to request access to a multi-user session by passing its *SOBJ* to a SIP proxy, which redirects the request to the edge agent controlling the access-router (agent) used by the receiver. In this agent, QUALITIS processes the received *SOBJ* and coordinates with other agents (using QUALITIS-P) the quality level to be assigned to the session on the path from its source (or HA in the case of mobile receivers controller by MIP). These actions are taken only over the new network branches.

The mapping mechanism gets, in a network edge, the *QSPEC* object of each flow and the information about the available classes, and maps each flow into the suitable service class. When the mapping process is not optimal, for instance due to a selection of an overloaded service class, the adaptation mechanism is triggered. The adaptation operates based on the *QSPEC* and on the current network conditions. A detailed description of QUALITIS operations, methods and examples are presented in [3].

IV. PERFORMANCE EVALUATION

The QUALITIS proposal was evaluated by using the *Network Simulator 2* (NS2). Each edge QUALITIS is implemented together with a resource allocation controller. QUALITIS in access agents are also placed together with SIP proxies. The resource controller provides notification about available classes as well as admission control and service class configuration. SIP proxies are used in access networks to receive SIP messages from receivers and to redirect them toward access agents. Regarding multimedia session support, the Evalvid tool [16] is used to control the video quality delivery along the end-to-end session path.

Simulations aim to analyze QUALITIS latency and to measure its impact on receivers' expectation. Users' expectation is analyzed by measuring MOS, PSNR, SSIM and VQM of a session with and without QoS adaptation. The MOS method is proposed by ITU, ANSI and MPEG to quantify the video quality based on the human quality impression. The PSNR evaluates frame-to-frame quality of the received sequence and maps the video into the MOS evaluation scale. The VQM verifies the session quality level based on human eye perception and subjectivity aspects, including blurring, global noise, block distortion and colour distortion. The SSIM metric is designed to improve the traditional PSNR, which is inconsistent with human eye perception. The SSIM metric is based on frame-to-frame measuring of three components (luminance similarity, contrast similarity and structural similarity) and combining them into a single value, called index.

Since Evailvid tool only supports non-scalable session, the following three QoS adaptation profiles are used to evaluate the QUALITIS proposal: (*i*) *N_ADP* profile, in which no QoS adaptation method and admission control is used. In this case, the session is accepted even when its full rate is not assured and packet losses are expected; *ii*) *ADP_Sub* profile, which re-maps all flows of a session to a less important class in order to avoid session blocking and keep the session with an acceptable quality level; *iii*) *Perfect* profile, which assures the session full rate and will be used as benchmarking (no congestion).

DiffServ and IEEE 802.11e are configured as QoS models and three generic classes were defined, named *Premium*, *Gold* and *Silver*. To avoid service class starvation, the maximum reservation threshold of each class is 20% for *Premium*, 20% for *Gold*, 20% for *Silver* and 40% for *Best-effort*. The *Premium* class is configured with the best QoS parameters in terms of loss, delay and jitter tolerance.

A *Variable Bit Rate* (VBR) non-scalable video session with an average rate of 51 Kb/s is used to analyze the impact of QUALITIS on receivers' perception. The video session, named "News" [18], consists of 300 frames with the YUV format, sampling 4:2:0, dimension 352x288, which was compressed through a MPEG-4 CODEC and sent with a 30 frame/s rate. The *Group of Pictures* (GOP) of the sequence is composed by 30 frames and each frame is fragmented in blocks of 1024 bytes. Based on previous studies [19], it is assumed that loss intolerance is the major session requirement. In this case, a loss limit of 2.5% is used as the maximum degradation allowed in the *QSPEC*. Besides this parameter, it is assumed that the *QSPEC* of each flow is randomly generated. Moreover, a congestion of approximately 15% is assumed in the preferred class (concurrent traffic).

The used topology was generated randomly by the *Boston University Representative Internet Topology Generator* (BRITE). The simulated scenario is composed by three networks with sixteen interior routers and three edges router in each network. One network hosts the source and another hosts the receiver. The propagation delay is assigned by BRITE according to the distance between each device. The bandwidth capacity of wired and wireless links is of 100 Mb/s and 11 Mb/s, respectively.

This set of tests aim to analyze the impact of QUALITIS on the users' experience, in the presence of congestion in the preferred wireless class. As explained before, this analysis is done based on measurements of QoE metrics (SSIM, MOS, PSNR and VQM), as well as QoS metrics (latency). The MOS metric quantifies video quality based on a scale from 5 (best) to 1 (worst). The SSIM and VQM were achieved by using the MSU Video Quality Measurement Tool 1.52 [20]. The VQM metric varies from 0 (best) to 5 (worst), while SSIM varies from 0 (worst) to 1 (best). The PSNR evaluates the quality of the received sequence and maps it to a MOS scale as shown in Table 1.

TABLE 1. PSNR to MOS conversion

PSNR (db)	**MOS**
> 37	5 (Excellent)
31 – 37	4 (Good)
25 – 31	3 (Fair)
20 – 25	2 (Poor)
< 20	1 (Bad)

Considering frames with MxN pixels and 8 bits/sample the PSNR is defined through the Equation (1).

$$PSNR = 20\log_{10}\left(\frac{255}{\sqrt{\frac{1}{MxN}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1}\left\|Ys(i,j)-Yd(i,j)\right\|^2}}\right) \quad (1)$$

In Equation (1), *Ys(i,j)* designates the pixel in the position (*i*, *j*) of the original frame and the *Yd(i, j)* refers to the pixel located in the position (*i*, *j*) of the reconstructed frame (on the receiver side).

The analysis of results reveals that QUALITIS introduces an average latency of 0.8% to configure QoS mechanisms and resources during session setup with all profiles. This value can be considered good and does not introduce long delay during the session setup time.

In addition, Table 2 shows VQM and SSIM values for *ADP_Sub* and *N_ADP* profiles. The VQM metric is kept with an excellent level when the *ADP_Sub* profile (average of 0.35) is used. The efficiency of the *ADP_Sub* adaptation method is confirmed by the measured SSIM (average of 0.99 - minimal video distortion).

TABLE 2. VQM and SSIM for *ADP_Sub* and *N_ADP* profiles

Profile/ Metric	**ADP_Sub**			**N_ADP**		
	MAX	**MIN**	**AVG**	**MAX**	**MIN**	**AVG**
VQM	0.6	0.12	0.35	5	0.4	3.2
SSIM	1	0.98	0.99	0.99	0.76	0.83

Fig. 2 shows the results obtained regarding the PSNR when *N_ADP*, *ADP_Sub* and *Perfect* profiles are used. Results reveal that the average PSNR with *N_ADP* is 20.1db, while 38.5db is the average achieved with *ADP_Sub*. Compared to a perfect match situation, the PSNR of a video sequence is reduced in 2% and 48% when QUALITIS is configured with *ADP_Sub* and *N_ADP* profiles, respectively. The good results with *ADP_Sub* are explained since QUALITIS keeps the video with an acceptable quality level by using resources available in another service class. The measured average PSNR is considered excellent according to the MOS scale.

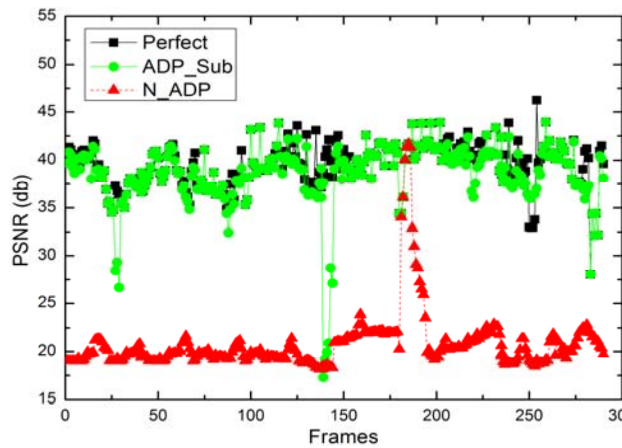

Figure 2. PSNR of each frame

With *ADP_Sub*, three major set of frames are lost in the middle of a video sequence (frames 27-29, 139-142 and 279-283) which reduces the quality perceived by the user. However, the user perceived quality is really impaired when the *N_ADP* profile is used, as illustrated by the frames shown in Table 3.

TABLE 3. Some frames of "News" with *ADP_Sub* and *N_ADP* profiles

Frame [293] – *ADP_Sub*	**Frame [293] – *N_ADP***
	

V. CONCLUSION and FUTURE WORK

The QUALITIS proposal controls mapping and adaptation operations for multi-user sessions, independently of the underlying QoS models and available service classes. The proposed session control scheme brings benefits to users and providers, because session blocking probability is reduced and the usage of network resources is optimized. The benefits for the end-to-end QoS control over heterogeneous networks is reflected on the session quality perceived by receivers.

Simulation results show that QUALITIS keeps multi-user sessions with acceptable quality level during congestion periods, based on a sub-perfect mapping (*ADP_Sub*). When such mapping profile is used, the average throughput is reduced only 2% when compared with a perfect match. This reduction of throughput has no negative impact on the quality perceived by the users. This result is confirmed by measurements of MOS, PSNR, VQM and SSIM: the MOS level is 5, and the average values measured for PSNR, VQM and SSIM are of 38.5db, 0.35 and 0.99 respectively.

In order to improve our findings, a heuristic approach to combine all adaptation profiles according to historic data and traffic patterns will be investigated. Moreover, QoS control operations will also be evaluated in mesh/sensor networks as well as in networks with different QoS models.

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