An Integrated Approach to Control the Quality Level of Multi-user Sessions

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ABSTRACT

A combined control of multimedia quality and network resource allocation is a core requirement for the deployment of communication services shared by multiple users (multi-user). The challenge resides in achieving a high number of satisfied users while saving the scarce network resources. This situation occurs due to the dynamic changes in resource demands, the existence of links with different capacities and the use of distinct QoS models along a session path. This paper proposes the *Quality of Service Control for Multi-user Sessions* (QUALITI) scheme to maintain multi-user sessions with acceptable QoS levels over heterogeneous networks, while optimizing the usage of network resources. QUALITI integrates QoS mapping and adaptation with network resource allocation along end-to-end session paths. QUALITI was evaluated through simulations that analyzed the convergence time, usage of network resources, throughput and one-way delay.

Categories and Subject Descriptors

C.2.3. [**Computer-Communication Networks**]: Network Operations – *network management, network monitoring.* Applications

General Terms

Performance.

Keywords

Content distribution; QoS Mapping; QoS Adaptation; Network Resource Allocation.

1. INTRODUCTION

There is a consensus that the quality level control for real-time sessions is a major requirement for the success of next generation IP access networks. Whereas keeping sessions with acceptable quality avoids losing clients, the correct control of network resources reduces waste and probability of blocking new requests, allowing more users to join the offered services. However, the combined control of session quality and network resource allocation is challenging due to unpredictable session requests, oscillations of network capabilities and re-routing, which can be generated by handovers or link/node failures.

The above challenges require more attention when session content is sent to multiple users (called multi-user sessions), which can be efficiently done through IP multicast or *Application Layer Multicast* (ALM) mechanisms. When the content is distributed over heterogeneous networks, QoS adaptation should not be done by the sender, since receivers and networks may have different capabilities. On the other hand, decoding/recoding the content between heterogeneous networks increase both complexity and delay of the overall system. Thus, we assume an adaptation mechanism based upon the use of scalable encoding (e.g., MPEG4) by sources, which allows encoding each session's content into a set of flows with well-defined priority, rates and requirements.

To allow scalable traffic differentiation and conditioning of different multi-user sessions (e.g., broadcast video and multimedia streaming), it is assumed that the wired network implements the *Differentiated Service* (DiffServ) model, and wireless links implement IEEE 802.11e. Such heterogeneity requires mapping flows of sessions into different *Class of Service* (CoS). This requires a mechanism for on-demand QoS mapping and shielding of devices, sessions and networks from the details of the underlying QoS infrastructure. This can not be done with static mapping approaches. Moreover, the oscillatory network behaviour (e.g., due to re-routing) may require complement QoS mapping with adaptation support to avoid session blocking while keeping accepted sessions with a useful QoS level.

This paper introduces *Quality of Service Control for Multi-user Sessions* (QUALITI) mechanism to control the QoS level of multi-user sessions by integrating QoS mapping, QoS adaptation and network resource allocation. The performance evaluation is done through two sets of tests that analyze QUALITI's benefits to control QoS level of sessions when experiencing link failure and handover. The

Conference Name: *QoSim 2008*, March 3, 2008, Marseille, France
Copyright number: ISBN 978-963-9799-20-2

first set of tests shows the session recovering latency from re-routing and the impact on resource allocation. The second set of tests shows some insights in the receptor's perspective through measurements of throughput and one-way delay.

This paper is structured as follows. Section 2 describes the related work. Section 3 introduces the QUALITI proposal. Examples of QUALITI operation are provided in Section 4, while QUALITI's performance evaluation is described in Section 5. Conclusions and future work are summarized in Section 6.

2. RELATED WORK

There are several proposals to control the end-to-end QoS level of sessions in networks with limited and changeable resources by controlling session rate or mapping the session to another network class. An example of those is N. Nasser [1] proposal to adapt QoS by allocating only a minimum bandwidth to sessions mapped to a congested CoS. When network resources become available, the QoS level of the sessions admitted at minimal rate is enhanced by allocating the maximum requested bandwidth. A session is dropped, not re-mapped to another class, if the minimum bandwidth of its class cannot be accommodated. This proposal does not avoid waste of resources upstream in the network, since the session rate is adapted only in the end device wireless link.

Other type of session rate control approaches [2] adapt the session QoS level based on receiver-driven functions. Since users may be far away from congested links or devices, they need to apply a trial and error adaptation mechanism to increase the session quality when network conditions improve. In contrast, transcoder-driven proposals [3] allow network devices to re-code multimedia sessions' content based on the available bandwidth, bringing the adaptation process close to the congested links. However, the use of transcoders makes network deployment dependent from the implementation of several different types of multimedia encoders. Furthermore, the upstream waste of network resources is also not avoided, since the session re-coding is performed near the bottleneck, not end-to-end.

A proposal to control the QoS level of sessions based on QoS mapping is proposed by Rajan *et al* [4]. This approach defines four DiffServ-based CoSs with different priority, and users select one class for each of their sessions. The session is rejected or re-mapped to the best effort class if the resources available in the selected CoS do not satisfy the bandwidth required for the session. The adaptation process depends on the manual selection done by the user. Moreover, this proposal does not recover the session full quality when resources assigned to more suitable CoSs become available again.

The described related work shows that the majority of the analyzed proposals do not assure the full QoS level of sessions when resources are made available again. Moreover, existing solutions do not avoid the upstream waste of resources, since sessions' full rate is reduced only near the overloaded link and not end-to-end. In addition, other schemes reduce the system flexibility, since they are dependent of specific multimedia codecs. Therefore, the QUALITI solution is proposed to overcome the identified limitations, keeping an acceptable QoS level of sessions while optimizing network resources.

3. QUALITI OVERVIEW

QUALITI controls the QoS level of multi-user sessions and dimensions per-class resources along heterogeneous paths by coordinating QoS mapping, QoS adaptation and resource allocation. QUALITI is based on a modular integration of session and network control components. The session control aims to setup multi-user sessions through QoS mapping and adaptation. The network control is responsible to adjust per-class resources used inside and between networks. The mobility support allows for QoS control of ongoing sessions after handover through cross layer interactions with seamless handover mechanisms. In networks without IP multicast, QUALITI coordinates control of network resources and setup of edge-to-edge IP unicast connections. Figure 1 shows the components which integrate QUALITI.

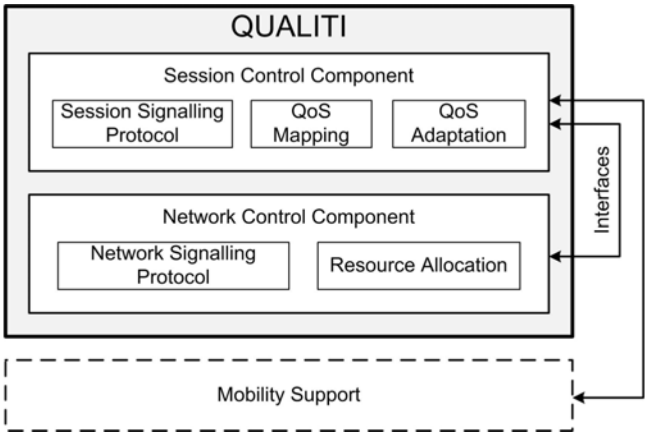

Figure 1. Components that integrate QUALITI

Each multi-user session is described by a *Session Object* (SOBJ), uniquely identified as proposed in the *Next Step in Signalling* (NSIS) framework [5]. The per-flow QoS requirements, such as bit rate, token-bucket, and tolerance to loss, delay and jitter, are described in the NSIS QSPEC object, which is part of the SOBJ. These values can be quantitative (e.g. ms or Mb/s) or qualitative (low, medium or high). QUALITI functionalities are implemented by agents located at edge and core routers. Whereas the former implement session and network control functions, the latter perform lightweight operations to configure per-class resources.

Communication between QUALITI components and existing solutions is allowed by mobility, access, QoS and routing interfaces. The *Mobility Interface* allows QoS control for ongoing sessions when using the bi-directional tunnelling approach to mobile multicast. Thus, QUALITI controls the setup of ongoing sessions on new paths, which can be performed in advance if, for instance, mobility prediction is supported. The *Access Interface* allows fixed or mobile users to access or leave multi-user sessions by using the *Session Initiation Protocol* (SIP). Thus, applications must compose a SIP message with the SOBJ in the *Session Description Protocol* (SDP), being received by a SIP-proxy in the access-network. After that, it forwards the message to a QUALITI agent based on the SIP Location Server, to install or to remove a session.

The *QoS Interface* is used to collect information about CoSs (loss, delay and jitter) on each network node. This interface is also used to allocate per-class resources in routers, by configuring their QoS schedulers. The wireless QoS support is taken by interacting with 802.11e *Medium Access Control* (MAC) elements. The *Routing Interface* is used to retrieve from the unicast routing tables' information about the network interfaces needed for processing QoS control. This interface also allows topology changes detection by intercepting routing advertisements generated by unicast routing protocols. For instance, a *Link State Advertisement* (LSA) is generated by *Open Shortest Path First* (OSPF) after receiving indications from low-level protocols whenever a network interface goes *down* or comes *up*. Upon intercepted an LSA, the core agent notifies ingress agents to re-route affected sessions.

3.1 QUALITI Mechanisms

This section describes the proposed signalling protocols and the QoS mapping, QoS adaptation, and resource allocation mechanisms.

3.1.1 Signalling Protocols

QUALITI defines two edge-to-edge signalling protocols given the separation of session and network control functions. The *Session Control Function Protocol* (SCF-P) follows a receiver-driven and source-initiation approach, being triggered at the access-agent nearest to a receiver. QUALITI mechanisms are then invoked at the agent nearest to the source, or at the first agent discovered with the requested session on the path towards the source. The *Network Control Function Protocol* (NCF-P) provides QoS support based on per-flow QSPECs and the conditions of the CoSs from ingress-to-egress/access points of a session. The separation between session and network signalling does not require end-to-end signalling for resource allocation. This turns deployment easier, since each network operator may use their own signalling approach, avoiding any impact on the operation of their neighbours.

SCF-P agents are implemented only in the edges, and keep per-session and per-flow state. NCF-P agents keep state about CoSs and edge-to-edge distribution paths in edge agents, and only per-class reservation state in core agents.

Figure 2 shows the signalling sequence introduced by SCF-P and NCF-P in a general scenario. When the QUALITI agent in the access-agent is triggered via the access interface to set-up a multi-user session, it verifies if the requested session is locally active. If so, all posterior requests for the same session are processed only by the access-agent. Otherwise, a SCF-P message is sent towards the session source. Upon receiving a SCF-P message, the ingress-agent tries to assure the correct mapping for each flow of the session. After selected the class, the NCF-P signals all agents along the ingress-to-egress path to allocate the required network resources. After successfully deployed the resource allocation, a NCF-P message is sent from the egress to the ingress agent to confirm the accomplishment of the requested operation.

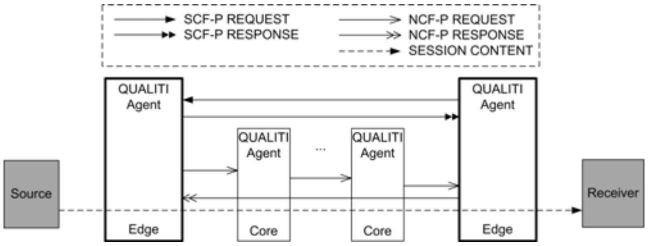

Figure 2. General signalling sequence introduced by QUALITI

The active state and resources are maintained by soft-state. Both protocols are being specified as a *NSIS Signalling Layer Protocol* (NSLP) to control multi-user sessions and resources.

3.1.2 QoS Mapping

The QoS mapping mechanism compares, one by one, the QSPEC parameters requested by each session-flow and the list of available CoSs. Afterwards, it chooses the suitable class for the requested session based on the proposed *Perfect*, *Sub-perfect* or *Hybrid Match* methods. The *Perfect Match* supports the full QoS requirements and bandwidth committed for all session-flows. When the preferred CoS cannot assure the maximum rate of the session, QoS adaptation is invoked to decide for sub-perfect or hybrid mapping. The *Sub-perfect Match* aims to map all session-flows into a CoS with QoS parameters different from those described in QSPEC, preventing session denials and re-ordering of packets. This method can be used in periods of congestion of the preferred CoSs, while keeping the session full rate. The *Hybrid Match* aims at allocating at least the high priority session-flows to the preferred CoS, mapping the remainder flows to a less significant class. It can be used when packet re-ordering is not crucial, such as with scheduled video and audio, in which cases it is more important to ensure an intelligible audio flow than a perfect video.

3.1.3 Adaptation Control

The QoS level of sessions can be adapted by *dropping or adding* (*ADP_Drop*) flows, based on their priority. When the maximum bandwidth of the preferred class cannot assure the QoS committed for a low priority flow, QUALITI removes this flow and classifies it in the sleeping state. Sleeping flows are re-activated (awaken) when network capability becomes available again and the session full rate is supported. The adaptation method can request re-mapping the session to another class using the sub-perfect (*ADP_Sub*) or hybrid (*ADP_Hyb*) mapping.

To minimize blocking probabilities while keeping sessions with acceptable QoS level, QUALITI agents can use a selective QoS adaptation scheme. This optional algorithm selects an already admitted session (or a set of sessions) and then decreases their QoS level (until the minimum acceptable rate specified in the QSPEC of those sessions) by dropping low priority flows or re-mapping them to other classes. This selection can be done randomly or using other fairness-based "adaptation weight" scheme, such as: *i*) High-rate: sessions with high-rate are selected. *ii*) Popularity-based: sessions with small audience (number of users) are selected [6]. *iii*) Price-based: sessions with low prices or with monetary incentives to be degraded are chosen [7].

If more than one session has the same adaptation weight, a random selection is applied based on the selective adaptation limit (∂_{adp}). The selective adaptation limit represents the percentage of admitted sessions that can be degraded. The fairness-based algorithm as well as the selective adaptation limit can be configured manually by the operator or on-demand based on usage data and traffic patterns. When an admitted session terminates or moves, the corresponding resources are released and the QoS level of adapted sessions is enhanced taking into account the configured adaptation scheme.

3.1.4 Resource Allocation

The resource allocation mechanism is based on a per-class reservation approach. In order to avoid class starvation, network ingress agents assigns each CoS, in the system bootstrap, with a minimum and a maximum reservation thresholds (*mRth* and *MRth* respectively). Whenever requested, QUALITI attempts to allocate the required amount of resources, which must never exceed *MRth*. However, this scheme can result in waste of resources, since requests can be denied due to the incapacity of a class to allocate resources above its *MRth. This incapacity occurs* even when the resources used by each remaining classes are below their *MRth*. QUALITI overcome this problem, by re-adjusting the *MRth* of the CoSs.

The main idea behind the CoS re-adjustment is to re-size the *MRth* of an affected CoS with the resources available in the remaining CoSs. Based on the function presented in (1), QUALITI computes the amount of bandwidth (*B_Rsz*) for re-sizing the *MRth* of CoS *j*. The *B_Rsz(j)* is the ratio between square of the available bandwidth (*Mrth-Bref*) and the *MRth. Bref is a* bandwidth reference for CoS *j*. This bandwidth reference can be either the *Brv* or *mRth* of class *j*, where *Brv* is the amount of bandwidth reserved. The *Brv* is assigned to the *Bref* when its amount is bigger than the *mRth* and vice versa, ensuring thus the committed rate.

$$(1) \quad B\_Rsz(j) = \frac{\left(MRth(j) - Bref(j)\right)^2}{MRth(j)}$$

The CoS re-adjustment is invoked whenever the amount of bandwidth required for a session-flow exceeds the *MRth* of the selected CoS, or when the selective adaptation limit is exceeded.

3.1.5 Overview of the QUALITI Operation

The SOBJs created by the sources are announced to the receivers by some type of off-line or on-line scheme (e.g., via HTTP or any session advertisement mechanism). Receivers use SIP to request access to a session by passing its SOBJ to a SIP proxy in their access network. This SIP proxy redirects the request to the access-agent that controls the access-point used by the receiver. After receiving a SIP message requesting the setup of a multi-user session, the QUALITI *session control* in the access-agent verifies, based on the SOBJ, if the requested session is locally active. If so, all posterior requests for the same session are handled only by this access-agent. Otherwise, a SCF-P message is sent towards the session source.

As a result of receiving an SCF-P message, the first ingress-agent found in the way toward the session source and holding the requesting session, invokes the *QoS Mapping* mechanism. This mechanism works based on the QSPEC of each session-flow and the per-CoS QoS capabilities. After selected the suitable CoS, the *network resource control* is invoked for resource allocation in the local network. Thus, NCF-P signals the data path inside the network, where each visited core-agent allocates resources described in the QSPEC. Upon receiving an NCF-P message, the egress-agent triggers the multicast routing protocol (e.g., PIM-SSM) to build the branches of the multicast trees associated with each session-flow. Afterwards, the egress-agent sends an NCF-P message back to the ingress-agent. If the reservation fails at any agent, the reverse-path to the ingress-agent is immediately signalled to restore the previous resource configuration. In a successful case, the ingress-agent sends a downstream

SCF-P message requesting all edge-agents to perform similar operations in their own networks. The access-agent attached to the receiver performs QoS mapping and resource allocation over the wireless link.

4. EXAMPLES OF QUALITI OPERATION

This session illustrates QUALITI operations to control the QoS level of multi-user sessions due to changing in path topology. One scalable multi-user session *M1* (supplied by the source *S1* connected to the ingress-agent *I1*) with three flows (*F1*, *F2* and *F3,* where *F1* has highest priority) is being subscribed by the receiver *R1*. The first example describes the operations accomplished due to link failure, with session full rate re-routing in the preferred class. The second example describes the behaviour to keep an ongoing session with acceptable QoS level due to an inter-network handover. The examples are not exhaustive and do not cover all QUALITI details.

4.1 Example of Multi-user Session Restoration

The operations to restore the full rate of session *M1* in an IP multicast enabled network, as a result of a re-routing event, is shown in Figure 3. After detected the LSA (event *1.1*), the core-agent *C1* reports the link failure to *I1* (event *1.2*). At *I1*, the resource allocation mechanism is invoked to restore the affected sessions (*M1* in this case) (event *1.3*). Firstly, QUALITI probes the resource capabilities of the bottleneck link on the new path by sending a *PROBE.Request* message towards *E1* (event *1.4*). The message carries its local per-class resource capabilities (in the QSPEC) and the IP routing alert option set. Upon receiving the *PROBE.Request* message, *C2* checks per-class bandwidth, delay, loss and jitter in local MIB and updates the message if that information is lower than the amount currently carried in the QSPEC. After accomplished the same, *E1* sends a *PROBE.Response* to *I1* (event *1.5*).

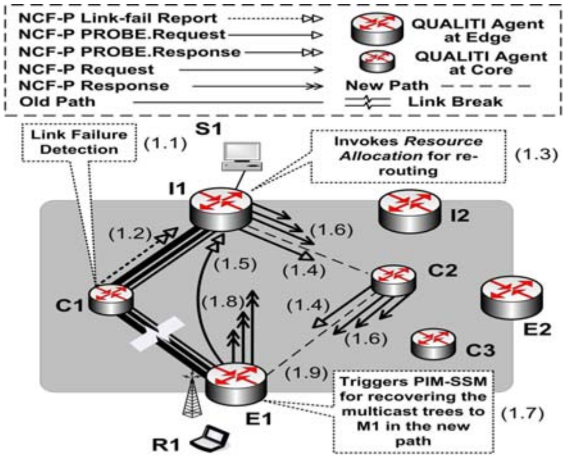

Figure 3. QoS adaptation by adjusting available resources among service classes

Based on the QSPEC transported in the *PROBE.Response* message and on the *MRth* of the preferred class, QUALITI in the ingress-agent *I1* verifies that the new path can accommodate all flows, and thus processes the resource request of *M1*. After succeeding, *I1* sends a per-flow *NCF-P.Request* to *E1* (event *1.6*). The agents *C2* and *E1* process the resource request of *M1* in the same way as *I1*. In addition, *E1* triggers PIM-SSM (event *1.7*) to create the required multicast branches. Subsequently, a *NCF-P.Response* message for each request (event 1.8) is composed and sent to *I1*, which then updates its local state.

Supposing that the link *C1*-to-*E1* becomes *up* again, QUALITI at core-agent *C1* reports this event to the all ingress-agents with sessions passing by C1, only *I1* in this example. After that, *I1* probes the QoS capabilities in the restored path's bottleneck. Based on the *PROBE.Response*, QUALITI in *I1* is informed that the QoS capabilities on the restored path are enough to accommodate *M1*. Consequently, *I1* invokes the *resource allocation* to setup resources for *M1* in the restored path. The state associated with *M1* on the path passing by *C2* is released by soft-state.

4.2 Example of Session Rate Control

The operations to control the QoS level of *M1* as a result of an inter-network handover of user *R2* is depicted in Figure 4. The mobility control is based on MIP bi-directional tunnelling, where the *Home Agent* (HA) and *Foreign Agent* (FA) are placed in ingress-points. Since handover controllers are not the focus of this paper, it is assumed the use of MIPv4. If MIPv6 would be supported, the FA would not be used. Thus, when *R2* moves to the access-agent *E4*, it receives a router advertisement message, acquires a care-of-address on the foreign network and registers its new address in the HA co-located with *I3* in network *N1*. After that, the HA at network *N1* notifies QUALITI agent at *I3* (event 3.1) to control the session QoS level on the path towards *E4*. Since it is assumed the use of bi-directional tunnels, the path *I1*-to-*E4* encompasses three multicast trees (one for each session-flow) from *I1* to *I3*, and three unicast flows in path *I3*-to-*E4*.

After successful mapping the QSPEC of the session in inter-network link *I3*-to-*E1*, all flows of *M1* are accommodated in the preferred class. After that, a *SCP-P.Request* message is sent to the next edge-agent *E1* (event *3.2*) to control the QoS level of *M1* on the remainder path. Upon receiving the message and after a successful mapping operation, per-flow resource allocation is requested in the selected class in the link E1-to-*I4*. However, the *QoS adaptation* mechanism in *E1* is notified that the preferred CoS cannot accommodate the lower priority flow of *M1*. Since QUALITI is configured to adapt the session by controlling the session rate, the session is not blocked. Hence, *E1* puts flow *F3* of *M1 in sleeping* state (event *3.3*), and the remainder downstream agents are signalled to control QoS level only for *F1* and *F2*.

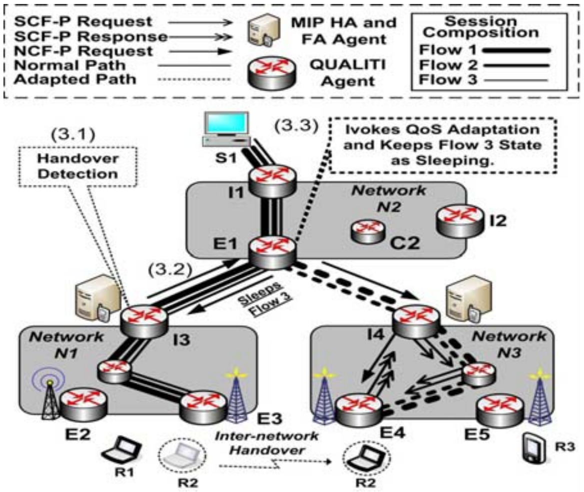

Figure 4. Illustration of QoS adaptation by dropping and adding low priorities flows

When the overloaded inter-network class becomes available, *E1* switches *F3* to *awaken* state and allocates resources of such flow along the path towards the receiver. On the other hand, when *R1* returns to its home network (procedure not illustrated), the session full rate is supported since there are available resources in the preferred class.

5. PERFORMANCE EVALUATION

The performance evaluation of QUALITI was carried out by using the *Network Simulator version 2.29* (NS-2.29), which constitutes a rich infrastructure to develop new protocols. Moreover, NS-2.29 provides opportunity to study large-scale protocol interactions in a controlled environment [8]. The simulation model includes traffic generators, which take a *Constant Bit Rate* (CBR) pattern, sending packets based on UDP connections, as well as network topologies randomly generated by the *Boston University Representative Internet Topology Generator* (BRITE) [9]. The network topology is composed by three networks (as shown in Figure 4), with bandwidth link capacity of 10Mb/s (wired) and 11Mb/s (wireless), and propagation delay generated by BRITE. The QoS support is provided by DiffServ and 802.11e, multicast by PIM-SSM and unicast routing by OSPF-LS. Each network has sixteen core routers and three edges. MIPv4 controls the mobility and receivers are connected to IEEE 802.11e wireless access-agents. In the ingress points, QUALITI is co-located with MIP HAs and FAs.

In order to achieve all functionalities required to accomplish the performance evaluation of QUALITI, the original NS-2.29 application suites were extended as in the following. The DiffServ was added with the WFQ discipline for QoS packet scheduling. Moreover, a PIM-SSM application was patched, since only the multicast applications originally available in NS-2.29 (DVMRP and PIM-DM) do not create multicast trees based on a MRIB structure. The OSPF-LS currently supported was modified in order to generate router-LSAs when a network link goes *down* and comes *up*. The network link was also modified to emulate the routing alert option, which is required by QUALITI to intercept the signalling messages. Finally, NS-2.29 was extended with QUALITI agents correctly placed in edge and core routers.

The simulation model comprises two set of tests to analyze the capability of QUALITI to control the QoS level of multi-user sessions due to re-routing. The re-routing is caused by a link failure in the first set of tests, and by handover in the second one. The first set of tests analyzes the impact of QUALITI by measuring the latency of the resource allocation mechanism. The second set of tests examines the impact on receivers' expectation, by measuring throughput and one-way delay of sessions with inter-network QoS adaptation.

The first set of tests analyzed QUALITI adaptation mechanism operating in the *ADP_Drop* profile, configured with ∂_{adp} of *25%* and *50%*. The second set of tests considered *ADP_Drop (0%)*, *ADP_Hyb* and *ADP_Sub* adaptation profiles. As suggested in [10], 20% of the link capacity is assigned as *MRth* for Premium (*Expedited Forwarding* (EF) alike class), Gold (*Assured Forwarding* (AF) alike class), and Silver (AF alike class) classes. The remaining 40% is used for Best-effort traffic. The Silver class is more tolerant to loss, delay and jitter, than Gold class. The *mRth* of each class is set to 50% of its *MRth*.

Each multi-user session is composed by three flows, with different priorities and rates (common in scalable codecs). The usage of three flows allows a good trade-off between quality and bandwidth, and additional flows only provide marginal improvements [11]. Each session-flow, starting from the most important to the less important one, has a *Constant Bit Rate* (CBR) of 32Kb/s, 64Kb/s and 128Kb/s, respectively. The loss threshold is of 2.5%, since previous studies show that in MPEG-2 with *Signal-to-Noise Ratio* scalability, 5% of losses in the most important flow results 100% of losses in all other flows [12].

5.1 QUALITI behaviour under link failure

This section shows how QUALITI controls QoS session quality under re-routing generated as a result of a link failure. Forty multi-user sessions are supplied, where each one is subscribed by one receiver following an exponential distribution. Twenty receivers are placed in each one of the two access-networks and at a distance of two networks from the sources. We assume that at instant 43s an intra-network link is broken, and thus, OSPF generates a *LSA*. As a consequence, some sessions experience congestion because they are re-routed to an overloaded path. The affected link is restored 32s later, resulting in another *LSA*.

Given that the forwarding tables are updated again, QUALITI is invoked re-route the sessions to their initial path according their arrival sequence.

Results reveal that when a link goes *down*, QUALITI takes around 24ms to restore each session on the new path. This convergence time encompasses session and network control functions, in which per-flow signalling is done to setup the required bandwidth along the new path. It means that the last session needs to wait about 480ms to be restored. QUALITI introduces 1% of latency to setup each flow on the new path compared to the flow RTT. If the simulation is scaled for 1,000 affected multi-user sessions (1,000 sessions are re-routed to the same path), the last session needs to wait 2,400ms for its restoration. The latency to re-route the sessions along the initial path when the previous broken link is restored is of 19ms per-session. This convergence time is smaller than the setup time thanks the different number of routers and link propagation delay along the paths.

The simulation results showing QUALITI operating with *ADP_Drop* (∂_{adp}) reveal that when ∂_{adp} = 25%, 85% of the re-routed sessions are accepted, being 24% with full rate (224 Kb/s), 64% with the two most important flows (96 Kb/s) and 12% only with the highest priority flow (32 Kb/s). In addition, QUALITI reduces the QoS level of 25% of admitted sessions during the congestion period. Naturally, since 25% of the admitted sessions are degraded, the per-session average throughput is lower, an average of 161.12 Kb/s, being the cost to pay for the admission of an additional number of sessions. In contrast, QUALITI operating with ∂_{adp} = 50% accepts 100% of the re-routed sessions, being 20% with full rate and 80% with the two most important flows. Moreover, only 43% of the admitted sessions were degraded. The average per-session throughput in the congestion period is of 148.86Kb/s.

Figure 5 and Figure 6 depict details in the resource allocation process after re-routing for *ADP_Drop(25%)* and *ADP_Drop(50%)* respectively. The graph (a) of both figures shows per-class resource manipulation (allocation and releasing) after detected a link *down* event. We can observe that between instant 48.8s and 49.1s, the resources associated with the less important flows are similarly put in *sleeping* (deleted) to accommodate affected (re-routed) sessions. As an example, at instant 48.8s, 128Kb/s allocated for the Premium class were released to accommodate 96Kb/s associated with the two-rate (96Kb/s) of a new session.

However, from instant 49.1s up to 49.3s, QUALITI with (*ii*) restores 15% more sessions since the resources released from the admitted sessions (43%) allowed support 20% of full-rate re-routed sessions and 80% of two-rate sessions.

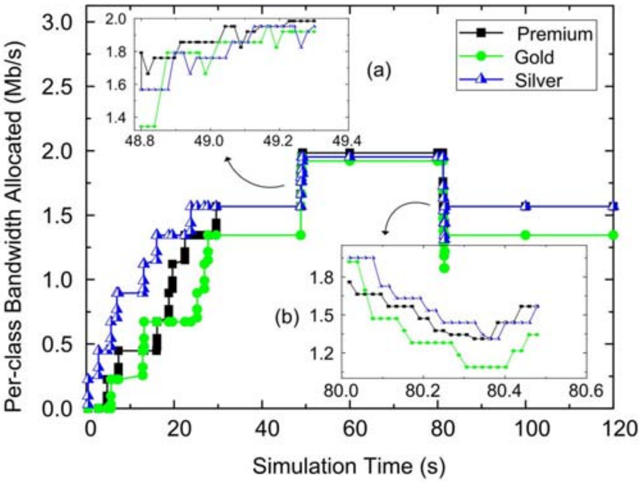

Figure 5. Per-class usage of resource when QUALITI implements a selective dropping of 25 %

The number of re-routed and re-allocated sessions after a link *up* event detection for QUALITI operating with (*i*) and (*ii*) is shown by graph (b) of Figure 5 and Figure 6 respectively. The per-class amount of resources associated with sessions re-routed to their initial path is comprised from 80s for both, and up to 80.36s (*i*) and 80.38s (*ii*). The re-allocation of each flow associated with a degraded session takes from 80.38s to 80.47s in (*i*) and from 80.40s to 80.55s in (*ii*). Based on these results, it is clear that QUALITI operating with (*ii*) takes more time to control the QoS level of the sessions. This happens since with a ∂_{adp} = 50% QUALITI accepts all sessions while degrading the QoS level of already admitted sessions.

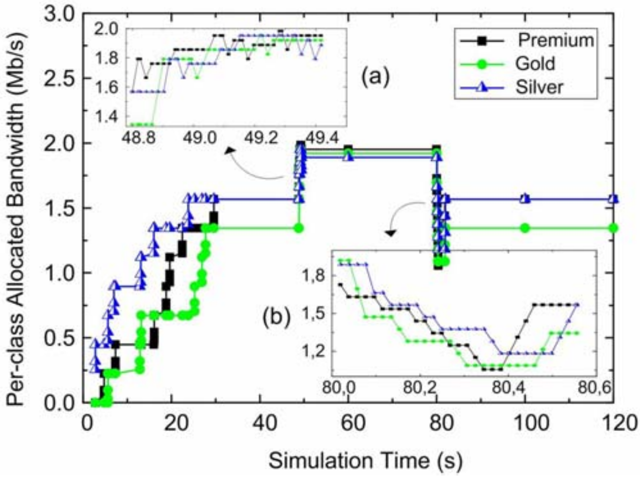

Figure 6. Per-class usage of resource when QUALITI implements a selective dropping of 50%

The evaluation of applying the selective dropping method shows that this scheme is able to improve the acceptance of new sessions while degrading the QoS level of existing sessions. Reducing the bit-rate of 43% admitted sessions, 20 new sessions are accepted, while the average per-session throughput after the selective adaptation process is reduced to 67%. Therefore, when the session full rate is not a critical requirement, the proposed selective dropping method allows for an improvement in network usage and user satisfaction.

5.2 QUALITI behaviour under handover

This section analyzes QUALITI when controlling the QoS level of multi-user sessions through *ADP_Drop (0%)*, *ADP_Hyb* and *ADP_Sub* profiles under re-routing events generated due to the handover of receivers. In this case, the home and foreign networks have ten and twenty receivers respectively. Each receiver subscribes one scalable multi-user session following the Poisson distribution. Each receiver moves from the access-agent at network *N1* to an access-agent at network *N3,* 25s after its subscription, and back to *N2* 65s latter. The movement pattern follows a constant speed of 30m/s, and the bandwidth required for all sessions exceeds in 12% the amount of resources allocated for all CoSs in the inter-network link (*N2<->N3*), causing 100% of session blocking.

For simplification, only the results measured for one receiver (*R1*) are considered due to the similar results of all receivers. The simulation results reveal that all profiles assure the session full rate when *R1* is connected to its home network. Figure 7 shows a detailed analysis of the throughput from the perspective of *R1*. In this case, the full rate of the joined session is guaranteed by the *ADP_Hyb* and *ADP_Sub* profiles in the foreign network. In contrast, the *ADP_Drop* profile only keeps the two-rate.

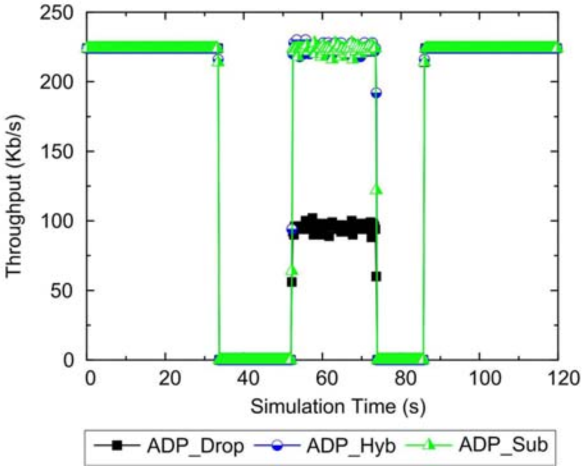

Figure 7. Throughput and latency in R1 with all profiles

The one-way delay of the session joined by *R1* is presented in Figure 8. On average, the one-way delay in the home network, where the session is mapped into the preferred class, is of 29.7ms

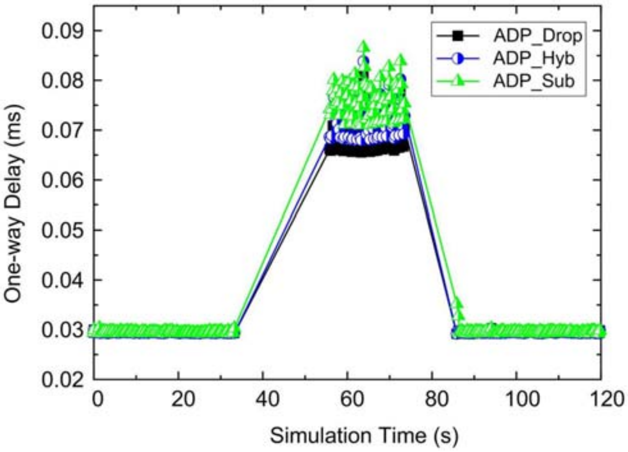

Figure 8. Delay and latency in R1 with all profiles

As a consequence of using MIP tunnels to encapsulate/decapsulate packets of the session, the one-way delay increased in the foreign network. In addition to the time consumed by the tunnels, the session adaptation to a service class that offers different delay tolerance also influences in the one-way delay. Thus, receivers need to wait on average 70ms, 73ms and 77ms when the *ADP_Drop*, *ADP_Hyb* and *ADP_Sub* profiles are being used, respectively. In the worst case, as occurs with the *ADP_Sub*, the receiver waits approximately 5% and 10% more to get the session in comparison with the *ADP_Hyb* and *ADP_Drop* methods respectively. However, this value remains acceptable, once they are in conformance with the session requirements filled in the QSPEC object.

This set of tests demonstrates QUALITI's ability in guaranteeing an acceptable quality level to ongoing sessions. The profiles *ADP_Hyb* and *ADP_Sub* distinguish them from the *ADP_Drop (0%)* profile by assuring session full rate, while the latter drops the low importance flow (128Kb/s).

6. CONCLUSION AND FUTURE WORK

QUALITI combines QoS level control of multi-user sessions and per-class resource allocation in heterogeneous networks. This control is performed based on the coordination of QoS mapping, QoS adaptation, and network resource allocation in unicast and multicast networks. The adaptation function controls the QoS level of admitted and re-routed sessions (due to re-routing events) by three possible methods: dropping the less significant flows of selective sessions (*ADP_Drop*), shifting some of the less important flow to a less suitable class (*ADP_Hyb*), or shifting all flows of the session to another class (*ADP_Sub*).

The simulations results show that QUALITI introduces a latency of 1% to assure the QoS level of a scalable session. In what concerns the performance of the adaptation function, it was shown, for instance, that a controlled degradation of part of ongoing sessions allows keeping all session with acceptable quality. Moreover, QUALITI was able to accept 50%, 85% and 100% of re-routed sessions when using a selective dropping profile of 0%, 25% and 50%, respectively. However, the average throughput when the selective limit is of 0%, 25% and 50% is decreases to 89%, 72% and 67% respectively.

The performance evaluation of QUALITI in controlling the QoS level of ongoing multi-user sessions reveals low latency to recover sessions on new paths (on average 0.09 %). The *ADP_Drop (0%)* profile minimizes the session blocking probability by reducing the session quality. However, *ADP_Drop (0%)* provided low throughput n comparison with the remaining profiles, since the lowest important flow is dropped in foreign networks, while the session full rate is assured by using resources allocated for other classes when the other profiles are used. The session one-way delay is increased in the foreign network due to the creation of MIP tunnels and it is also influenced by the QoS profile method used in the system.

As future work, heuristics for the combination of all adaptation profiles according to information about previously used data and traffic patterns will be investigated. In what concerns resource allocation, a class-based over-reservation scheme combined with admission control will be analyzed. Finally, an alternative approach for the sequential session restoration handling will be verified to improve the system scalability.

7. ACKNOWLEDGEMENTS

This work was done at the Laboratory of Communications and Telematics of the Faculty of Science and Technology of the University of Coimbra. It is supported by DoCoMo Euro-labs, by the Portuguese Ministry of Science, Technology and High Education, and by European Union FEDER - POSI (projects Q3M and SAPRA).

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