QMoEs: A Bandwidth Estimation and Monitoring Tool for QoE-Driven Broadband Networks

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Abstract— **The multimedia landscape is evolving towards more customized services which imply increasingly stringent requirements on networks. The triple-Play environment is insufficient to adapt to each requested service and deliver it over the Internet with guaranteed Quality of Experience (QoE). Next Generation Networks (NGNs) are tackling this limitation bringing together well-known QoS mechanisms which may increase the range of personalized media services over fixed access in a cost-effective way. The RUBENS (Rethinking the Usage of Broadband access for Experience-optimized Networks and Services) initiative defines a new network architecture which gathers most relevant QoS mechanisms to improve users' end-to-end QoS. In the context of these QoS mechanisms, we present the QMoEs utility (Quality Monitoring and Estimation): an Available Bandwidth Estimation Tool (ABETT) integrated within the RUBENS framework to enhance (together with other RUBENS' mechanisms) the delivered QoS and performed QoE. Our study is practically relevant as it does not limit to the implementation and evaluation of QMoEs performance. Besides the QMoEs evaluation through an extensive simulation study using OPNET, this work also explains how QMoEs is embedded within a particular architecture, aspect which reference ABETT implementation studies do not consider.**

Keywords— **QoS, QoE, Active Estimation, Bandwidth Management, OPNET Simulation, NGN Architecture.**

I. INTRODUCTION

Customized multimedia services are rapidly evolving towards an "*as you wish/when you wish*" concept, unveiling to Telecom new business opportunities. This service evolution implies an increase of traffic content (e.g. video streaming, peer-to-peer, etc.) whereas end-users are still tied to best-effort networks which provide them with an unstable Quality of Service (QoS). A sheer increase of multimedia content and the need for personalization pushes the boundaries of what current Quality of Experience (QoE) architectures can support.

Providing new services through the Internet enables Telecoms higher flexibility degree. Also Triple-Play networks offer limited non-customized quality for certain applications which do not require dynamic configuration [1]. Moreover, network deployments entail high CAPEX investments that Telecoms are reluctant to carry out. Thus, it is currently complicated to guarantee end-to-end QoE while providing multimedia services through the Internet.

One possible solution might consist of network over-provisioning. Nevertheless, a more suitable solution considers that functional network blocks are responsible for resource management and QoS provisioning through engineering techniques. This alternative has been barely addressed and major efforts are required to solve the content provision problem and achieve acceptable end-user QoE levels.

RUBENS project [1], proposes an architecture framework (Fig. 1) which aims to define and evaluate a new broadband access infrastructure that offers personalized QoE in a flexible way for a large variety of applications, delivery models, and devices. RUBENS includes several mechanisms which dynamically optimize end-user experience. One of these key mechanisms consists of providing available bandwidth measurements of a certain path of interest and to react to unexpected quality degradations in the RUBENS network.

In this paper we propose a novel end-to-end ABETT called Quality Monitoring and Estimation (QMoEs), not as a generic mechanism, but as a key component embedded in the RUBENS architecture, adapted to the specific requirements that network architecture and services demand. To this end, we introduce the RUBENS architecture overview and define the specific role of QMoEs to preserve services' QoE. Moreover, we explain RUBENS requirements in terms of the relevant metrics to be enhanced while implementing the estimation tool. We provide simulation results to quantify the goodness of QMoEs within the RUBENS context and finally, we derive conclusions and open work guidelines.

The remainder of this paper is organized as follows: A revision of literature in terms of most recent ABETTs' implementation is provided in section II. Section III describes the basics of RUBENS architecture and functional blocks which take part in the cross layer interaction together with the ABETT. In section IV we detail the scenario and platform features and we evaluate our mechanism via OPNET. Section V concludes the paper.

II. ABETTS RELATED WORK

Most accepted classification comprises active ABETTs in two groups: PGM (*Probe Gap Models*) which bases the estimation on the dispersion gap between two consecutive probing packets and PRM (*Probe Rate Models*), whose estimations rely on sending trains of probe packets at increasing rates.

Recent ABETTs implementation methodologies have considered several assumptions and start-up hypothesis which might not represent real network conditions: for example, common to all PGM methods is the assumption that the tight link and the narrow link of a path match up. Nevertheless, it

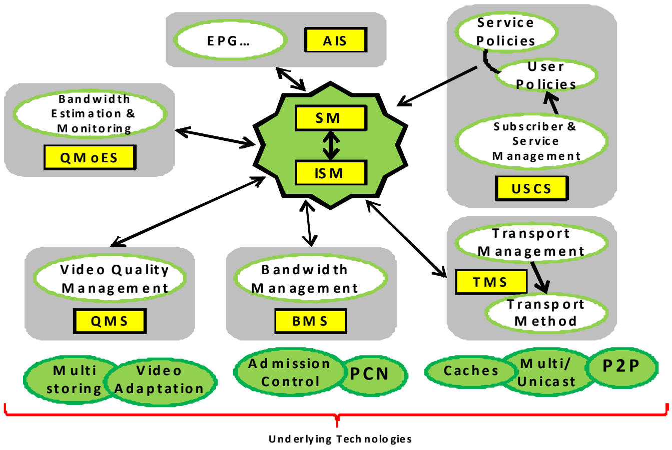

Fig. 1 RUBENS network architecture

has been proven [2] that it does not work in high capacity multi-hop scenarios. Thus, PGM methods have not been considered for the QMoEs implementation focusing our efforts on PRM tools.

Another limitation which strongly determines ABETTs' behavior, is the cross-traffic model performed to collide with probe-traffic. In [3] the cross-traffic model assumed is conformed based on 700 bytes fixed-size packets sent at a certain CBR rate which clearly does not represent real cross-traffic conditions. The same problem appears in [4]. The cross-traffic model proposed is based on a 2001 study, which does not reflect current multimedia traffic patterns.

The proposed testbed configurations for ABETTs' validation suffer from obsolescence as well: recent literature remains tied to network models whose paths barely achieve some dozens of Mbps, meanwhile aggregation and core networks already support about Gbps path loads. For example in [5], authors perform a study based on a hidden Markov chain model which presents a testbed with a maximum capacity of 10 Mbps.

It is therefore not clear if most actual proposed ABETTs are suitable enough to be employed and carried to NGNs infrastructures. In the following sections, we present QMoEs tool in the context of the RUBENS architecture. There are several differences between previous works and the work presented in this article. First, we particularize our ABETT to the specific requirements of RUBENS, enhancing those metrics which are relevant to this novel architecture. Second we do not assume a generic cross-traffic model, but we use the OPNET "*Application Utility*" to configure video and voice cross-traffic. Finally, we consider high capacity paths (order of Gbps load) in medium and high level congestion situations.

III. RUBENS ARCHITECTURE

The objective of RUBENS is to define and validate an access network architecture that takes service requirements and evolutions. Main services considered are multimedia contents, especially *Video on Demand* (VoD), since VoD represents one of the most attractive services in the current business landscape. Taking this into account, the RUBENS network provides a novel environment to boost service delivery opportunities in a cost-effective and dynamic way.

A. RUBENS' Functional blocks overview

RUBENS architecture has been deployed attending to the services (mainly video multimedia) to be provided and specific broadband access network functionalities. In order to clearly define the variety of RUBENS interactions, network mechanisms have been gathered in seven main blocks depicted in Fig. 1:**Application Interface Subsystem (AIS)** provides a direct link between the features of an application and the overall RUBENS function. The **Quality Management Subsystem (QMS)** is a service-specific subsystem that allows selecting and tunning the parameter settings of a service to increase/decrease the quality level. The **Bandwidth Management Subsystem (BMS)** is responsible for managing the bandwidth of a service class between end points. The **Transport Management Subsystem (TMS)** manages the different transport mechanisms that can be used for different services. This includes selecting the transport means itself (e.g. unicast/multicast, progressive download, P2P). The **User and Service Control Subsystem (USCS)** role captures the constraints that are put on the mediation functions. Service policies and user policies are cached within this block so that the services' behaviour is offered based on users´ contract and *Service Level Agreements* (SLAs). The **Mediation functions** constitute the architecture brain. They take decisions based on the input of AIS, BMS, TMS, QMS, and QMoEs. The responsibilities have been splitted into two functions: the **Inter-Service Mediation (ISM),** which manages the overall delivered quality per access line and the **Service Management (SM)** which manages individual service sessions based on a limited set of parameters (required quality, required bandwidth, policies, etc). To this target, the SM interacts with QMS/BMS/TMS. Finally, the **Quality Monitoring and Estimation (QMoEs)** is responsible for providing available bandwidth estimations in order to inform to the SM and ISM functional blocks about end-to-end path throughput and hence, modify QMS, TMS and BMS behaviour in case users' perceived quality experiences certain degradation.

B. RUBENS requirements and relevant ABETTs' metrics

ABETTs methodologies state that there must be a trade-off among the reference metrics: *Accuracy*, *Estimation Time* and *Intrusiveness* [6] determine the goodness of a bandwidth estimation method. Researchers have performed interesting solutions focusing on these metrics, striving to achieve a tool where all metrics were simultaneously improved. However, as it is explained in [2], there is neither the necessity, nor the opportunity to propose an estimation tool which strengths these contradictory metrics simultaneously. Depending on the network technology and services which are being provided over the system, some of these metrics could even be relaxed. Thus, in this work, it has been first characterized the RUBENS network requirements to subsequently identify which metrics are desirable improve.

RUBENS aims to provide of dynamical optimized QoS to end users while delivering personalized contents.

Thus, *Accuracy* is strong significant to keep suitable QoE levels with reliability. Considering real time to be dynamically adapted to network conditions, the *Estimation Time* is also crucial to enable the system rapidly react to unexpected QoS variations which may impair users' service perception.

Other metrics to be considered while evaluating an ABETT are *Intrusiveness* and method *Scalability*. These metrics are not so critical in the validation process, despite the fact that minimizing their impact is desirable too.

C. *QMoEs integration and interaction within RUBENS architecture.*

RUBENS makes use of QMoEs to monitor ongoing path sessions over the architecture, from bandwidth estimations. In case of insufficient QoE, the mediation function (SM) triggers the QMoEs to estimate the available bandwidth of the path over which the service is being provided; the QMoEs pushes this information towards the SM to update the service session with a new set of parameters (based on input from BMS, QMS, TMS) bringing the QoE to an acceptable level again. All in all, the QMoEs is a RUBENS mechanism responsible for providing QoE-related information from ongoing sessions in the network. Together with other functionalities, the QMoEs aims to build QoE optimization for different service delivery models. These measurements are forwarded to the Service Management System (SM) brain, to provide a dynamic solution for the provisioning of services with optimized QoE.

IV. SIMULATION PLATFORM

In order to carry out the QMoEs tool design, we have analysed interesting and suitable characteristics of most recent PRM tools, looking forward to reach a reasonable trade-off among the main evaluating metrics.

To this target, it has been proposed a simulation scenario which reflects RUBENS architecture conditions. The aim is to mimic its behaviour and study whether or not QMoEs provides suitable bandwidth estimations. The simulation platform has been splitted into two separated stages (Fig. 2): A first stage consists of an *OPNET Modeler* based scenario which collects temporal data measurements from the injected probe traffic (*TRX mechanism* in Fig. 2). The second part of the process has been implemented by using *MATLAB* and it carries out a translation of these temporal data into available bandwidth estimations (*RCV mechanism* in Fig. 2).

A. *OPNET platform and parameter configuration*

The OPNET simulation platform consists of an access network composed of several access nodes and a core node which represents the core network. Several end-users share video baseline traffic through the paths which comprises the RUBENS network. The video sharing process has been configured in the *Application* and *Profile Definition* available OPNET utilities which enable to simulate different content types (Video streaming VoIP, etc.) and congestion levels (medium and high). Medium congestion level means that the tight link of the path of interest presents 40% of available bandwidth. High congested path presents 20% of available bandwidth in the tight link. The end-to-end paths configured among users, present high capacity levels; the narrowest link is 1 Gbps capacity. There exists an additional set of parameters which determine the QMoEs behaviour too:

1) Probe-traffic model: the traffic configured to estimate the ABW consists of trains of 1500 bytes size packets (the MTU supported by Ethernet networks and most popular size in bandwidth estimation works [7-9]). The number of packets per train has been empirically set to 200. Two packet-train configurations have been studied: uniform and sectored patterns. The uniform train pattern configures packet-trains at a uniform rate from a range between two defined thresholds. The sectored model divides the probe rate spectrum (between the same thresholds) in several sectors coffering different probabilities to them. The number of trains configured with the same probe-rate varies according to the probabilities empirically stated.

2) Queuing model: The FIFO queue model has been considered as a reference in ABETT studies and testbed environment validation [10]. Thus, we have also included this characteristic for the simulation performance.

3) Cross-Traffic behaviour: The majority of the cross-traffic packets that flows through the network only share with probe-traffic packets one hop of the path. It is important, since this behaviour matches what takes place in Internet.

B. *Simulation start-up*

Probe-traffic packets are injected and time-stamped at the *SRC* node. According to the path of interest, the probe-traffic reaches the *DST node* where is time-stamped as well. This temporal information is collected in a text file, which serves as input for the *MATLAB* platform where the *RCV mechanism* is deployed.

This mechanism carries out the following functions: packet-loss detection, confidence intervals determination, smooth filtering process and temporal measurements translation into bandwidth estimation outputs and main validation metrics results. Fig. 2 summarizes the described process.

V. SIMULATION RESULTS

As it has been previously pointed, the main metrics of interest are Accuracy and Estimation Time. Fig. 3 shows the mean available bandwidth estimation for medium and high congestion levels. The x-axis represents the number of packets per probe train. The figure shows the real known ABW (discontinuous trace), and the estimated ABW for two different probe-traffic configurations: The black trace represents packet-trains uniformly distributed and the grey trace corresponds to a sectored probe-traffic pattern. For the medium congestion situation, both probe-traffic patterns present a good performance obtaining values close to the real ABW. Nevertheless, in high congested situation, the uniform probe-traffic distribution presents an oscillation which does not fit RUBENS requirements. On the other hand, the sectored shaping presents smother behaviour.

Closely related to previous figure, are mean relative error (*Accuracy*) results. The relative error has been obtained as

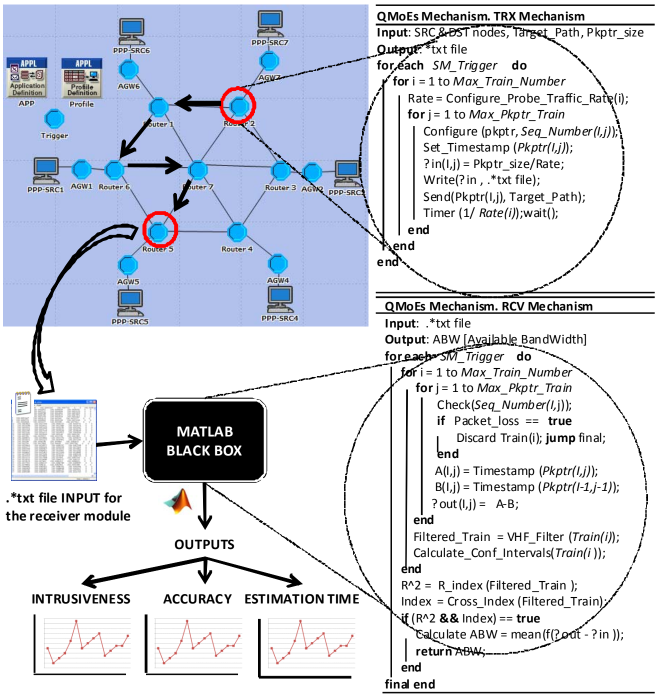

Fig. 2 OPNET and MATLAB simulation platform for QMoEs validation.

well, for medium and high congestion situations as a function of the number of probe packets configured per train and confidence intervals set to 95%. The relative error does not exceed 10% for any packet-train configuration at medium congestion levels. For high congested situations, 175 and 200 packets-per-train configurations, present a good performance (under 15% of relative error), so that RUBENS network requirements are accomplished in terms of precision.

The mean Estimation Time to obtain one bandwidth measurement is 2.301 seconds. This also represents an encouraging result since the method can rapidly provide bandwidth estimations and consequently react in real-time to sudden impairments on RUBENS network.

RUBENS architecture has been conceived as a broadband access network with high capacity end-to-end paths. Taking this into account, RUBENS has been thought to support 1 Gbps end-to-end link capacities. According to the *Intrusiveness* definition proposed in [6] QMoEs *Intrusiveness* (nearly 35 Mbps during the 2.3 seconds of measure process), can be considered that it does not represent a significant limitation in case the tight link is not congested, but it can be considered intrusive while having a high congested end-to-end path. Nevertheless, *Intrusiveness* is not as critical *Accuracy* and *Estimation Time*. Despite of the fact that further research is required to obtain a better performance in terms of *Intrusiveness*, the presented results are encouraging to provide with accurate bandwidth measurements and dynamically react to network impairments.

VI. CONCLUSIONS AND FUTURE WORK

This paper introduces QMoES, an end-to-end PRM active available bandwidth estimation tool based on a sectored probe-traffic pattern. Also novel to this work is that we do not

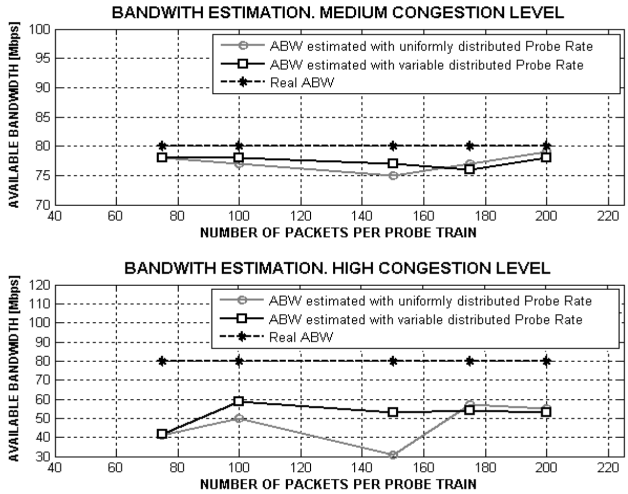

Fig. 3 Available bandwidth for medium and high cross-traffic congestion configurations. Uniformly and sectored probe-traffic patterns.

limit to perform the ABETT, but we also define the specify applicability that performs, in the context of the RUBENS architecture and adapted to its concrete requirements.

Simulation results indicate that QMoEs present a good performance in terms of *Accuracy* and *Estimation Time* which validates the ABETT within the RUBENS framework. We plan to add control nodes to decrease method *Intrusiveness.*

Nevertheless, current ABETTs evaluation studies show that bandwidth estimation tools are far from being ready, since the three main metrics are contrary: a bandwidth estimation tool which facilitates efficient, accurate, non-intrusive and robust measurements still remains challenging.

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