QoE-Aware Routing for Video Streaming

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***Abstract*—In this paper, we introduce a novel QoE-aware routing approach for video streams. Our approach monitors the network conditions in real-time and dynamically makes adaptive routing decisions based on predictions of end-user perception of video quality. This video quality is quantified by Mean Opinion Score (MOS). The experimental results show that our proposed approach leads to a good trade-off between the QoE expected by the end-users and resource utilization.**

***Index Terms*—Traffic-aware routing, Quality of Experience, Video streaming.**

I. Introduction

In recent years, Internet Service Providers (ISP)s have faced a rapid growth in the amount of data traffic on the backbone networks. This expansion is largely attributed to the rise of new usages such as video streaming. According to Cisco forecast [1], video traffic will account for up to 80% of all consumer Internet traffic in 2018, up from 66% in 2013. To cope with this increasingly demand for bandwidth, ISPs must improve the actual configuration of their network by implementing congestion control strategies to enhance the quality experienced by the end-users (Quality of Experience — QoE) while at the same time avoiding the over-provisioning of transmission links.

In this paper, we focus on traffic-aware routing, in particular on the introduction of QoE-awareness for accounting for the users' perception when making routing decisions. Traffic-aware routing is a mechanism used to make adaptive routing decisions with regard to the current utilization level of the network resources. The goal in taking bandwidth into account when computing routes is to shift some flows away from the heavily used paths where congestion will first occur. Traffic-aware routing aims at satisfying the QoE requirements expected by end-users by providing a sufficient level of Quality of Service (QoS) on each communication link.

Despite all the efforts, most of the existing solutions are aware to QoS and very few takes into consideration the QoE. QoS-aware solutions are hampered by the difficulty to define the exact and complete expression of the user QoS requirements [2], so as to establish a correct trade-off between resource utilization and the satisfaction of users. Depending on the application, acceptable perceived quality can be achieved even if the QoS metrics are not so good [3]. By adopting QoE to the routing algorithm, better resource utilization can be achieved while, at the same time, respecting a given target in terms of the QoE expected by the end-users. In an attempt to address the research gap, we introduce a novel traffic-aware routing approach based on real-time estimates of the QoE observed by the end-users. Our approach monitors the network conditions and dynamically makes adaptive routing decisions based on predictions of end-user perception of video quality, which is quantified by Mean Opinion Score (MOS).

II. QoE-aware routing approach

Our QoE-aware routing approach consists of three main stages: monitoring, modeling, and routing decisions. First, it performs measurements on the on-going traffic and delivers three measured metrics: the packet arrival rate, the packet loss rate, and the packet loss burstiness, denoted by X, LR and $MLBS$, respectively.

The second stage starts by characterizing the current evolution of LR as a function of X. More precisely, we intend to find a single approximate law that fits with the measurements. We denote this latter law by Q so that $LR = Q(X)$. To do this, we used the method proposed by *Ammar et al.* [4]. We automatically discover a queueing model that reproduces as well as possible the behavior of each transmission link within an ISP network. In our work, we consider a single server queue model with a finite buffer space, namely, the *M/G/1/K* queue. Note that, Q needs to be regularly updated (say, every 20 seconds) in order to take into account the actual variations on the traffic conditions.

The discovered queueing model Q plays a key role in predicting the expected loss rate among each link of a routing path. Let $\widehat{LR}_P^i$ be the expected value of packet loss rate at the i^{th} node in the path $f_{s,d}$ under the hypothesis of a new incoming flow, with a peak rate r, is directed to this path. Then using our approximate law Q we have:

$$\widehat{LR}_P^i = Q_P^i(X_P^i + r) \tag{1}$$

where X_P^i reflects the throughput of the on-going traffic at the i^{th} node in the path P, and Q_P^i defines the evolution of LR_P^i against the throughput X_P^i.

It follows that, in order to implement the QoE-aware routing, we need to be able to accurately estimate the perceived quality of the video streams, in real-time. To do this, we use the Pseudo-Subjective Quality Assessment (PSQA) approach presented in [5]. Briefly, PSQA allows for the creation of parametric QoE models, usually mapping QoS and application-layer parameters to the measures of perceptual quality, typically MOS values. The mapping can be implemented with a variety of statistical learning tools. The PSQA estimator used in this paper is a simplified version of the one proposed in [6], in which one of the application-layer parameters is fixed to a medium value, and the resolution is chosen among a possible set of values according to the observed bit rates (in the examples described below, the resolution is fixed, but in actual usage, it could be estimated in real-time from the observed traffic). The model used considers four inputs, namely, the aforementioned video resolution and quantity of movement, and the loss process in the network, characterized by the loss rate and the mean loss burst size. Therefore, the PSQA estimator becomes:

$$\widehat{MOS} = F(RES, QM, LR, MLBS) \quad (2)$$

where RES can be estimated from the observed bit rate for the flow, QM is fixed, $MLBS$ is measured from the network, and LR is derived from the queueing model as described above.

Finally, the routing decision can be formalized as: a new incoming video is directed to the path P if

$$\widehat{MOS}_P \geq T_{mos} \quad (3)$$

where $\widehat{MOS}_P$ corresponds to the minimum MOS value encountered along the path P, and T_{mos} represents the MOS threshold. Otherwise, this flow will be redirected to another path that fulfills this latter condition. Note that, when there is no alternative path with acceptable MOS, we forbid this flow from entering the network since the available networking resources are deemed insufficient.

III. Numerical Results

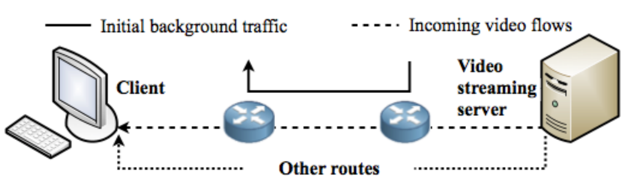

Fig. 1: On-going traffic conditions over the network

The network topology of our experiments is shown in Figure 1. The capacities of the links are equal to 10 Mb/s. The size of each buffer is set to 20 ms and the queueing discipline is FIFO (*First In First Out*). We evaluate the performance of our approach using ns-3 simulations. Each simulation is run for a period of 10 minutes. It is also worth nothing that we benchmark our approach against an *oracle*, which represents an unrealistic traffic-aware routing solution. This oracle accepts the maximum number of videos over a routing path, thus achieving the maximum workload, while successfully meeting the QoE target.

The ongoing traffic consists of two components. An initial background traffic, which is not subject to any traffic-aware routing control. We represent this initial traffic by a real traffic trace [7]. In our experiments, we adjust this trace by scaling it down such that its average rate of transmitted packets is equal to 4 Mb/s. In addition to this initial source, the ongoing traffic is also composed of incoming video flows that requests access to the network. Each incoming video is represented by a real MPEG-4 video trace. The statistical properties of the generated video traces are available at [8]. Video traces arrive randomly to the communication path according to a Poisson process with a constant rate equal to 0.18. Their durations are drawn from an exponential distribution with mean of 60 seconds. The average rate of the transmitted packets of the aggregated video traces is approximately equal to 0.28 Mb/s.

TABLE I: Performance of our QoE-aware routing approach.

Routing approach	Utilization rate	Violation rate
Oracle	0.58	0%
QoE-aware	0.55	9%
No-control	0.76	73%

Table I relates the performance of our proposed approach with regards to the MOS target, $T_{mos} = 3$. Firstly, the results show that the oracle leads to an average utilization rate equal to 0.58. Secondly, they indicate that our approach yields satisfactory results since it leads to an utilization rate (*i.e.*, 0.55) close to the one delivered by the oracle. Thirdly, they also imply that our approach fulfills the MOS threshold about 91% of the time. Finally, when the traffic-aware routing is inactive, the MOS threshold is severely violated.

IV. Conclusion

In this paper, we introduce a novel QoE-aware routing approach based on real-time estimates of the QoE observed by the end-users. The experimental results show that our proposed approach leads to a good trade-off between the QoE expected by the end-users and resource utilization.

Acknowledgment

This work was carried out during the tenure of an ERCIM "Alain Bensoussan" Fellowship Programme. The research leading to these results has received funding from the *European Union* Seventh Framework Programme (*FP7/2007-2013*) under *grant agreement* n°246016.

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