

Adaptive video streaming and fixed-mobile convergence: A good team to reduce power consumption and improve users' QoE

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ABSTRACT

The evolution of novel access networks is dominated by two major changes: first, an increasing convergence of fixed optical and mobile wireless access networks (driven by the industry interested in mutualizing infrastructure); and secondly, a surge in video traffic (expected to represent 80 percent of all consumer Internet traffic in 2019). This motivates the introduction of video delivery optimization in the design of the novel fixed-mobile convergent access to obtain more energy efficient networks with better Quality of Experience (QoE) perceived by the end-user. In this paper, we study how the joint optimization of video adaptive streaming decisions (like the video bit rate selection) and access resource allocations (like optical and radio equipment placement) could yield to maximize the QoE at the same time as power consumption is reduced.

Keywords: video streaming, fixed-mobile convergent access, energy consumption, quality of experience.

1. INTRODUCTION

The share of video streaming in the Internet traffic is growing at a blistering pace: “Globally, IP video will represent 80% of all traffic by 2019, up from 67 % in 2014” [1]. The most important share of video traffic already comes from services such as Youtube or Netflix. As expected, the tremendous increase of mobile devices (tablets, smartphones, laptops) is being accompanied by the rise in mobile video traffic (i.e., video travelling over 3G or 4G cellular networks) that will account for 17% of all consumer Internet video traffic by 2019, while “Video will be 72% of global mobile data traffic by 2019, compared to 55% at the end of 2014” [1].

For access networks (both cellular and fixed), the witnessed surge of traffic is accompanied by a growth in the power consumption motivating the need for improving the energy-efficiency of aggregation and access networks. A promising solution is the Fixed-Mobile Convergence (FMC) paradigm [2],[3], whose principle is to manage jointly the heterogeneous access technologies (e.g., optical, WiFi, 4G) in a unified optical network. FMC thereby allows to consolidate within the cloud fixed and mobile optical head-ends as well as base station (base band) processing to significantly reduce costs and power consumption through the mutualization of physical resources (in particular, optoelectronic converters and cooling infrastructure).

Given that the access/aggregation will carry the increasing video demands, we present in this article a general framework for a content- and energy-aware management of the novel convergent access/aggregation network. Most of Internet video streaming corresponds to so-called HTTP Adaptive bit rate Streaming (HAS), which employs the MPEG-DASH standard. This standard lets the video bit rate to be adapted over time to, e.g., best fit the bandwidth available to the client. Having such an IP-based video delivery therefore allows for a unified form of content to serve any sort of screen (Smart TV, STB, tablets, Web apps, etc.) from any type of access (cable, DSL, cellular, satellite). The main contributions of our work are:

1. We combine in an objective function both the users' perceived Quality of Experience (QoE) and the network operator's energy expenditure. The complete model incorporates the video management decisions (video bit rates) into the network planning and management (IP grooming into optical channels, wavelength assignment, optical path routing and opto-electronic converters placement).

2. We solve the problem on realistic network scenarios (urban, semi-urban and rural configuration with corresponding video demand), and show that our approach allows to obtain greater energy savings and better end-users QoE than traditional non-coordinated approaches like [4], where traffic demands are considered in terms of data rates only (bits per second). In our coordinated approach, the requested rates of HAS video demands are instrumented, and hence the aggregated traffic demand itself becomes a variable, instead of an input parameter. In particular, we show how energy consumption is limited and QoE is preserved when the video demand increases, compared to a legacy approach agnostic of content type [4].

2. FORMULATION

Let us present the system and its model. Let $G(N,L)$ be the graph of the tree topology where N is the set of nodes and L is the set of unidirectional fiber down links. We consider a set $E^F \in N$ of optical head-ends connecting FTTH/B subscribers, and a set $E^M \in N$ of cellular base stations. The set of all these end points is denoted as $E = E^F \cup E^M$. These different access networks are aggregated by a set $N^I \in N$ of intermediate nodes, connecting them to the (regional) Point of Presence (PoP) of the higher hierarchy level. PoP is hence considered as the source of all traffic. We refer to [3, Fig. 1] for conciseness. Operator $|\cdot|$ denotes the cardinality. Each intermediate node is assumed to have capacity of hosting an unlimited number of Virtual Digital Units (VDUs), each capable

of generating the base band signals, thereby alleviating the base stations from heavy processing and saving cooling energy. We consider the Common Public Radio Interface (CPRI) for transporting these base band signals from the hotels to the base stations. CPRI signals can go only through one lightpath and we consider a wavelength cannot multiplex CPRI and non-CPRI flows or other CPRI signals [4]. We hence assume mobile processing in the cloud, which requires strict delay limits. For this reason, any lightpath from node $i \in N^I$ to $e \in E^M$ cannot overcome a certain CPRI reach.

The demand is materialized by the average number of parallel video requests v_{eu} issued (over a certain time period) by node $e \in E$, with $u \in U$ where U represents the set of video resolutions (360p, 720p, 1080p in sec. 3). For every $u \in U$, q_{ur} denotes the QoE of a video encoded at resolution u and bit rate r (q_{ur} is usually a log-like function of r , more details are given in sec. 3 and Fig. 1). Each q_{ur} is also averaged over video categories (cartoon, documentary, sport and movie in sec. 3), reflecting the heterogeneous viewing context (screen size and video content type). The exhaustive list of notation is provided in Table 1.

Table 1. Model notation

Input parameters	Decision variables
v_{eu} : no. of videos of resolution u requested from end point e	$x_{eur} \in [0,1]$: fraction of videos of resolution u and rate r destined to $e \in E$
q_{ur} : QoE of video encoded at resolution u and bit rate r	$x_{ijeur} \in [0,1]$: fraction of x_{eur} carried on the lightpath between i and j , $i \in E$, $e \in E$
C^{BS} : cooling consumption per base station if BBU not deported	$z_{ieur} \in [0,1]$: fraction of videos of resolution u and rate r destined to e carried on CPRI from i , $i \in E$, $e \in E^M$
C^{HT} : cooling consumption per hotel	$z_{ie} \in \{0,1\}$: indicates if i hosts BBU of base station e , $i \in E$, $e \in E^M$
C^{VDU} : consumption per VDU	$z_i \in \{0,1\}$: indicates if i is the host of at least one deported BBU, $i \in E^I$
C^{OEO} : consumption per optical-electronic-optical converter	$a_i \in \{0, E^M \}$: number of VDUs needed at node i to accommodate all desired BBUs, $i \in E^I$
C^{OSW} : consumption per optical switch	P_{ij}^{IP} : set of lightpaths between i and j , $i \in E$, $j \in E$
C : capacity per wavelength (Kbps)	P_{ie}^{CPRI} : set of lightpaths capable of bearing CPRI signals between i and e , $i \in E$, $e \in E^M$
C_v : computational capacity per VDU (Kbps)	W : set of wavelengths
	U : set of resolutions
	R : set of video bit rates
	L : set of links
	$y_{pw} \in \{0,1\}$: indicates whether path p is assigned to wavelength w

The objective is to choose the equipment placement, flow routing and video bit rate to maximize a weighed sum of the aggregated QoE and the total power consumption:

$$\max[\alpha \text{QoE} - \beta \text{Pow}] \quad (1.0)$$

Parameters α and β are used to convert both components above into dollars, so as to get the same units and expose the financial interest for network operators. The expressions of the other factors are as follows.

$$\begin{aligned} \text{QoE}(x) &= \sum_{\substack{e \in E \\ u \in U \\ r \in R}} v_{eu} q_{ur} x_{eur} & \text{Pow} &= \text{Pow}^{BS} + \text{Pow}^{HT} + \text{Pow}^{VDU} + \text{Pow}^{OEO} + \text{Pow}^{OSW} \\ \text{Pow}^{BS} &= \sum_{e \in E^M} C^{BS} z^{ee} & \text{Pow}^{HT} &= \sum_{i \in N^I} C^{HT} z^i & \text{Pow}^{VDU} &= \sum_{i \in N^I} C^{VDU} a_i & \text{Pow}^{OEO} &= \sum_{\substack{p \in P \\ w \in W}} C^{OEO} y_{pw} & \text{Pow}^{OSW} &= \sum_{i \in N^I} C^{OSW} z^i \end{aligned}$$

The constraints to the optimization are:

$$\sum_{j \in E} (x_{ij}^{eur} - x_{ji}^{eur}) = \begin{cases} x_{eur} & \text{if } i = \text{PoP} \\ -x_{eur} & \text{if } i = e, \quad e \in E^M, u \in U, \\ & r \in R, i \in N \\ 0 & \text{otherwise} \end{cases} \quad (1.c1) \quad \sum_{r \in R} x_{eur} = 1, e \in E, u \in U \quad (1.c2)$$

$$\sum_{j \in E} (x_{ij}^{eur} - x_{ji}^{eur}) = \begin{cases} x_{eur} & \text{if } i = \text{PoP} \\ -z^{ieur} & \text{otherwise} \end{cases}, \quad e \in E^M, u \in U, \quad r \in R, i \in N \quad (1.c3) \quad \sum_{i \in N^I} z^{ieur} = x_{eur}, \quad e \in E^M, u \in U, \quad r \in R \quad (1.c4)$$

$$\sum_{\substack{u \in U \\ r \in R}} z^{ieur} \leq |U| z^{ie}, \quad i \in N^I, e \in E^M \quad (1.c5) \quad \sum_{i \in N^I} z^{ie} = 1, e \in E^M \quad (1.c6)$$

$$\sum_{e \in E^M} z^{ie} \leq |E^M| z^i, \quad i \in N^I \quad (1.c7) \quad \sum_{\substack{e \in E \\ u \in U \\ r \in R}} v_{eu} b_r x_{ij}^{eur} \leq \sum_{\substack{p \in P_{ij}^{IP} \\ w \in W}} C y_{pw}, \quad (i, j) \in N \times N \quad (1.c8)$$

$$\sum_{p \in P_l} y_{pw} \leq 1, \quad l \in L, w \in W \quad (1.c9) \quad \sum_{\substack{u \in U \\ r \in R}} v_{eu} b_r z^{ieur} \leq \sum_{\substack{p \in P_{ie}^{CPRI} \\ w \in W}} C y_{pw}, \quad i \in N^I, e \in E^M \quad (1.c10)$$

$$\sum_{\substack{p \in P_{ie}^{CPRI} \\ w \in W}} y_{pw} \leq 1, \quad i \in N^I, e \in E^M \quad (1.c11) \quad \sum_{\substack{u \in U \\ r \in R}} v_{eu} b_r z^{ieur} \leq C_v a_i, \quad i \in N^I \quad (1.c12)$$

Constraints (1.c1)-(1.c2) (resp. (1.c3)-(1.c7)) are the flow constraints for the traffic destined to fixed (resp. mobile) end points. In particular, constraint (1.c6) enforces that the BBU of a BS must be hosted somewhere, be it at an intermediate node or at the base station itself (legacy case).

Constraints (1.c8)-(1.c9) represent grooming of IP flows, while (1.c10)-(1.c11) represent grooming of CPRI signals: (1.c9) enforces that a CPRI signal cannot be multiplexed on the same wavelength, with other CPRI or IP flows. Finally, (1.c12) determines the minimum number of VDUs needed to accommodate all deported BBUs.

3. RESULTS

In this section, we describe the tests conducted to evaluate our proposal. First, the testing scenarios are detailed. Second, the numerical results of these tests are discussed.

We consider three different topologies and six different video traffic loads, defining 18 tests. Each topology is a randomly generated multi-stage tree, corresponding to one of the geotypes (Dense-Urban, Urban and Rural) defined in [5]. To generate these trees, we follow the method detailed in [3] using the values shown in Table 2. The CPRI reach is fixed to 2 km.

The video traffic loads are normalized with respect to a reference video demand. We assume that all the end points of the same type (fix or mobile) generate the same amount of video requests. Thus, the reference number of video demands v_{eu}^{ref} of resolution u requested by a given node e are computed as $v_{eu}^{ref} = n_e s_u f_u$, where, n_e is the number of active users at node e , s_u is the share of users with a device with resolution u and f_u is the video frequency (i.e. average number of videos played by user) of users with a device with resolution u . For mobile and fix end points, we use 100 and 2032 (800 households with 2.54 users per household [6]) as values for n_e , respectively ([7]). For the sake of simplicity, we assume that each resolution u is representative of a given device, namely, we consider that 360p, 720p and 1080p corresponds to smartphone/tablet, browser and connected TV, respectively. Under this assumption, we use Table 3 from [7] to fix the s_u and f_u values. Once obtained the reference v_{eu}^{ref} , the six video loads are generated as $v_{eu} = \rho v_{eu}^{ref}$, where the load factor ρ ranges from 0.5 to 3 with a step of 0.5.

We characterize the QoE as a q_{ur} function of both the rate r and the resolution u , using the Video Quality Metric (VQM) score [8], which is a full-reference metric with a higher correlation with human perception. Since the VQM score ranges from 0 to 1, representing the best and the worst QoE, respectively, we associate QoE level with $(1 - VQM)$ score. In Fig. 1, we plot the QoE functions employed in this work. They have been generated as the average of the 360p, 720p and 1080p curves plotted in the four subfigures in [9, Fig. 2].

The values used for the contributions to the power consumption are shown in Table 4 [3]. Finally, the parameters α and β (ratios between \$ and objectives) are set to \$2/W [10] and \$0.0076/video [11], respectively.

We evaluate our proposed content-aware solution (model in section 2), against a benchmark unaware of content type (traffic demands modeled in bps) corresponding to the unrestricted ‘‘bypass’’ case of [3]. To make a fair comparison, we generate the benchmark solutions with the same optimization model, by fixing the video rates for each 360p, 720p and 1080p video to 100kbps, 2000kbps and 3000 kbps, respectively, corresponding to a QoE of 0.85 for all three resolutions. Fig. 2 represents the assessment of our proposed solution under two forms (one form per row) for each scenario (one scenario per column): the first row depicts the value of the objective achieved when the video load increases, while the second row represents, with a scatter-plot, the trade-off obtained between aggregated video quality and total power consumption, the tag of each point being the load.

In all three scenarios, we observe the gain in objective value with the content-aware solution increases with the video load, ranging between 8% and 13% for Dense Urban, between 3% and 21% for Urban and 9% and 30% for Rural. The absence of benchmark data for video loads higher than 2 in Rural is due to a problem infeasibility (not enough infrastructure for the total rate). We observe that the content-aware approach however not only is able to find a solution, but is also able to maintain the increase in objective gain. This is obtained by trading off video rates to still serve the requests while controlling both the video quality and power decrease.

Table 2. Topologies parameters

Geotype	DU	U	R
Cell sites density (/km ²)	10	3.5	0.15
Households density (/km ²)	400	900	300
	0		
# Mobile endpoints (E_F)	10	7	3
# Fix endpoints (E_F)	5	2	8

Table 3. Video traffic parameters

Device	Smartphone /tablet	Browser	Connected TV
Share of device (s_u)	0.61	0.16	0.23
Video frequency (f_u)	9.3	4.7	10.7

Table 4. Power consumption values

Parameter	Value
C^{BS}	600 W
C^{HT}	500 W
C^{VDU}	100 W
C^{OEO}	15 W
C^{OSW}	50 W

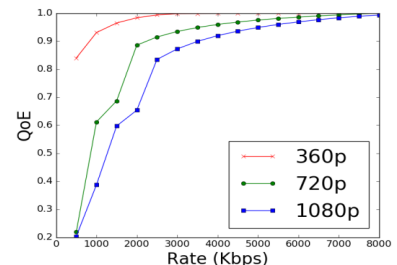


Figure 1: QoE curves

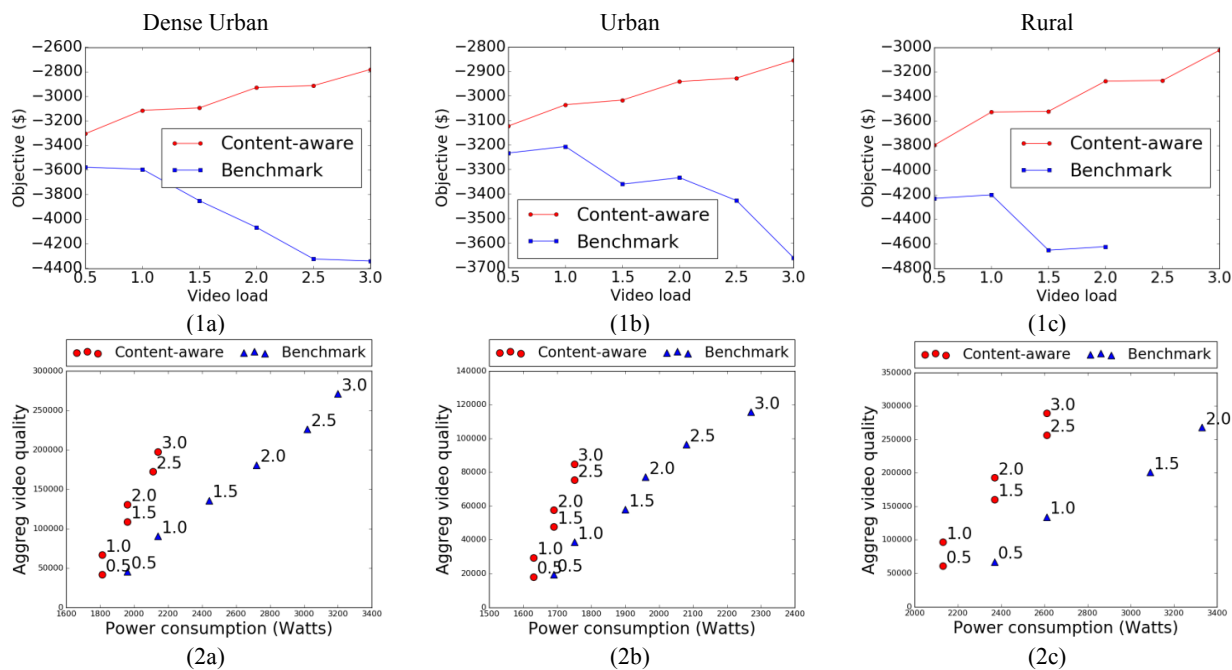


Figure 2: Comparison of the proposed content-aware solution with the benchmark from [3], for all the scenarios.

Despite in Fig. 2.2a-c we observe that, for a given video load, the aggregated video degradation is the same order as that the decrease in power consumption (ranges in 10%-34% for DU, 4%-26% for U, 8%-29% for R), this is only a consequence of the chosen α , much lower than β in the objective: with more stringent requirements in terms of QoE for the network operator (change of the objective), the proposed model shall be able to exploit the sub-linear decrease of QoE in bit rates, for high bit rates (see Fig. 1).

4. CONCLUSIONS

By shifting the network planning constraint from the traffic demand to the video quality demand, we have made the case for a content- and energy-aware management strategy of FMC networks. This strategy aims at accommodating best the nature of the predominant traffic share, video being expected to reach 80% of Internet traffic in the next few years. We show such planning allows to scale quality and energy savings with the video load increase, compared to legacy approaches.

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