Studying Green Video Distribution as a Whole

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Abstract

This paper highlights the current trends and the necessary research directions for achieving carbon-effective streaming services. Cooperation between the vendors of the end-to-end delivery pipeline is encouraged to design standards and technologies.

1 Introduction

The video streaming community has been challenged to become greener by reducing electricity consumption and carbon emission. The researchers in the area have, in particular, struggled to address the problem *as a whole*. Multiple operations are implemented in an end-to-end pipeline to transport the content from the camera where it is initially captured to the screen in which it is consumed, as represented in Figure 1. This functional pipeline involves several inter-connected actors (vendors), which run the software, operate computing infrastructure, and store large amounts of data. To reduce the carbon footprint, the community should not only commit to efforts in each component of this pipeline, but also implement a coordinated global action. In this paper, we introduce two main research directions for studying green video distribution as a whole.

As the first direction, we emphasize the need for better practices to share metrics among the actors. The ongoing research to measure, analyze, and model energy consumption metrics is a first step. Some papers have proposed generic models, which combine the consumption and average performance values [18] and introduce a power model of more instantaneous consumption and performance variations [14]. We call now for the definition of standards and protocols to share these data between actors. By exposing these metrics and tracing the energy consumption, based on specific models, all actors in the pipeline could take well-informed actions.

Second, we highlight the complexity of the relations between the actors. Some recent trends in the sector (see Section 2) tend to dilute the responsibility for energy consumption among many actors, who have complex interplay in both business and technology sides. When analyzed from an energy perspective, the economic principles behind these relations are yet to be developed. The literature addresses the carbon footprint reduction from the standpoint of one actor. For example, some papers have focused on the Content Delivery Network (CDN) [17, 21, 11], while some others have dealt with client-side algorithms to find a tradeoff between improved Quality of Experience (QoE) and the energy consumption of ABR [20, 13]. Some recent studies [15, 19], which analyze ABR strategies in relation with CDN or with encoders, are one step closer to the multi-vendor perspective. However, we must approach the carbon emissions problem from a broader perspective. We are in particular interested in modeling the behaviors of economic actors and studying the potential impact of regulations in the area. By applying global constraints, the regulators can generate major disruptions in the economic and technology equilibrium [12].

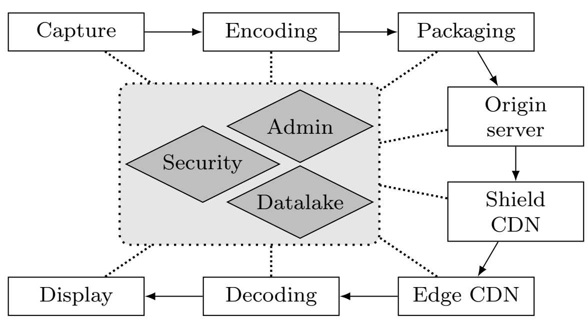

Figure 1: Functional video delivery pipeline. White boxes are the data-plane; Gray diamond boxes are the control-plane.

In this paper introduce some of the technology and business trends that may impact the research toward sustainable video streaming. Then, we identify some gaps, which, in our view, are critical for consideration by the entire streaming community. We encourage actions in the regarded standard and scientific research.

2 Context and Trends

This section underlines three industry trends, which make the challenge of monitoring the streaming footprint a hard global problem.

The first trend is the multiplication of files that are generated and delivered per video asset. The main driver of this multiplication is the widely adopted Adaptive Bit Rate (ABR) delivery technique. Other drivers include the different ABR formats, the rights protections, and video codecs. File multiplication increases carbon consumption since it needs more processing power and more storage to create and serve the representation ladder. Furthermore, our analysis of large-scale production live video services revealed that the majority of the segments are never requested [4], therefore a part of the pipeline shown in Figure 1 is wasted. When accounting for carbon footprint, it is common to count the energy of a complete video segment delivery, but counting the non-delivered segments is usually omitted.

Another trend in the streaming industry is the implementation of multi-vendor strategies. While not new [9], this trend has amplified in the latest years due to several reasons. First, service providers implement load-balancing and offloading algorithms to mitigate the risk that one single CDN vendor fails or reaches its capacity limits. The community has recently released new standards [8] and launched an open-source initiative [7] to implement multi-CDN strategies. Second, the development of the Open Caching protocols [6] has enabled the interconnection of CDNs by allowing one CDN to deliver content on behalf of another CDN. Tracking the global energy consumption of a streaming service is harder when multiple interconnected vendors contribute to the delivery.

We finally highlight the decoupling between software and infrastructure. The video industry has embraced cloud-based techniques, where containerized software runs on a shared physical infrastructure, which is managed by either cloud providers or Internet Service Providers (ISPs). For example, a hybrid CDN combines a set of servers deployed in the ISP network and some physical resources that are available on-demand in external datacenters, typically during an event causing a traffic peak. This decoupling also makes the monitoring of energy consumption harder.

3 Research Directions

3.1 Energy Consumption as a Whole

The research community has recently studied the problem of conveying metrics and logs related to every delivered video segment. The Common-Media-Client-Data (CMCD) [1] and Common-Media-Server-Data (CMSD) [2] specifications have shown promise in making this possible. A working group is now preparing a specification for *request tracing*, which is expected to enable any actor in the pipeline to trace a request and share metrics with the other actors involved in the delivery [3]. Unfortunately, the traced metrics are related to QoE and not to energy consumption. We call for adding energy consumption to the reported metrics so that the global impact of every request can be logged from end to end.

Per-request tracing is unfortunately not sufficient. Another crucial, though often overlooked, aspect in determining the energy consumption of a global video streaming pipeline is the omission of specific components. It takes at least three forms.

First, the control-plane (see Figure 1) typically contributes to the total energy consumption of the pipeline, but this contribution is hard to quantify if we stick to a request-based measure. Indeed, the control-plane is a key, always-on, support for administering, securing, and monitoring the delivery pipeline. We need to relate this energy consumption to another unit of delivery. Furthermore, we need to report this consumption globally.

A second omitted factor of energy consumption comes from the segments that are not consumed. As mentioned in Section 2, a fraction of the segments are never requested, although, in the traditional streaming approach, these segments have been prepared and stored. Some new approaches have been recently explored, for example, the *just-in-time* technique, which dynamically creates the content upon request [5]. This promising technique should now apply to all components of the pipeline. We call here for a better reporting of the energy consumption related to non-requests, which should complement the aforementioned request tracing initiative.

Finally, some components are traditionally assessed with metrics based on delivery performance rather than delivery efficiency. For example, a CDN cache server is measured by the *hit-ratio*. For a given caching policy, the bigger the storage, the higher the hit-ratio, but the higher the carbon footprint and energy consumption. The most popular content is worth storing since many requests benefits from its presence in the cache. However, many segments are stored but never requested before their eviction. We emphasize here that we miss metrics to measure relative resource waste, which is again not related to an existing request but rather to a non-existing one.

3.2 Actor Behaviors and Regulations

Green-compliant actions by a streaming service often come from or are at least incentivized by regulations at a governmental level. With the analysis of the technical context and trends above, setting up rules towards a global green video distribution can be possible. Theoretically, the general scientific framework is the so-called *mechanism design* [16, 10] derived from game theory, consisting of establishing mechanisms for which actors naturally adopt the *right* actions (*i.e.*, those for the good of society). Additionally, even if such rules can be defined, we also need to study what happens if some actors are encouraged to act in a *green* way and others are not, a situation representative of an international internet network where regulation could only be implemented in certain areas.

The external infrastructure providers (EIPs) should be accountable and transparent on the *energy source* of their resources, allowing streaming services to monitor and calculate their end-to-end environmental costs accurately. The related standard groups must act to make this accessible since upcoming regulations aimed at reducing carbon emissions could result in the implementation of requirements for EIPs and streaming services to use sustainable sources. Moreover, as such regulations emerge, the carbon efficiency of an EIP can become a significant benchmark in the domain.

Finally, from the perspective of end-users, the carbon consumption of streaming services may influence their choice. Since no video services have claimed a green approach yet, we cannot assume the behavior of the end-users when offered the option of opting for greener video services. We call, however, for more transparency from the service providers by exposure of their content-based carbon footprint data. Additionally, end-users may be offered a range of options for selecting content quality based on the carbon footprint of each representation. They may opt for content with a lower carbon footprint while accepting an adequate QoE trade-off.

4 Conclusion

This paper takes a step into green video streaming. We identify the current trends and main research directions, in our perspective, are crucial prerequisites to achieving carbon-effective streaming services. We encourage each member of the video streaming community to discuss and/or design regarded standards and technologies ensuring acting as a whole. For future work, we plan to measure and analyze each step of end-to-end video streaming, starting from our domain, CDNs.

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