End-to-end Optimizations for Green Streaming

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ABSTRACT

Video streaming is a widely used and energy-demanding online service, which contributes to CO2 emissions and environmental issues. In this paper, we investigate the technological feasibility and benefits of green streaming technologies, which aim to optimize the energy efficiency and carbon footprint of streaming content across the whole supply chain. Our work focuses on three key technologies: context-aware encoding, green media players, and energy-aware content steering. We present experiments and simulations to evaluate the performance and impact of these technologies. We also explore their economic viability and potential for creating new business opportunities in the streaming industry. Our work provides a holistic evaluation of green streaming technologies, which can support the global efforts for climate action and environmental protection.

CCS CONCEPTS

• **Information systems → Multimedia streaming**.

KEYWORDS

streaming, sustainability, artificial intelligence, video encoding, content distribution, media player

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1 INTRODUCTION

There is a growing concern for the industry, private households and standardization over how streaming applications contribute to global warming. According to the International Energy Agency, 72% of the energy consumed in streaming is attributable to user devices, 23% to transmission and 5% to datacenter-based processing [5]. According to an article by the BBC [4] , the Internet accounts for around 4% of global greenhouse gas emissions. This emission is similar to the contributions of the global airline industry. Streaming media accounts for 60-80% of the global Internet traffic and continues to grow steadily. Emerging applications stream content at higher resolutions and frame rates, and new applications such as the metaverse, virtual reality and industrial (IoT) video will further accelerate the demand. In this paper we highlight three ideas and solutions to our green streaming approach: Context-aware encoding, green media players and energy-aware content steering.

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2 CONTEXT-AWARE ENCODING

The technical complexity of video sequences depends directly on the type of content. For example, content with fast image changes (e.g. sports, action) is more complex to encode than news broadcasts with a constant-color background. In addition, the distribution of content and its consumption on end devices with different form factors affects the overall energy requirements of the streaming value chain.

To solve these issues, in previous work we have examined the effect of context-aware encoding methods on power consumption, using an AI-based per-scene encoding solution [8] to decrease bitrates and adapt to different screen sizes. As part of the measurements on end devices, we concluded that "that the complexity of a scene has almost no influence on power consumption compared to brightness and contrast. Even the size of the TV panel itself it and their power efficiency overrules any potential savings through optimized content encoding". Therefore potential gains are possible in encoding components. It was shown that using AI-based Per-Scene Encoding to lower the bitrates and resolutions for each scene can reduce power consumption. HD encodes need (on average) 3 watts (9%) less power, and 4K/UHD encodes need (on average) 69 watts (30%) less power than using a standard encoder for the same scenes. Additional measurements for savings in distribution and storage are planned for the future.

3 GREEN MEDIA PLAYERS

While encoding usually only happens once for a given content, it can be consumed by millions of devices and players. Our early measurements showed that the complexity of a scene and therefore its bitrate only has a minor effect on power consumption. This can be attributed to hardware-accelerated decoders available to most platforms and codecs. However, the display brightness of device significantly contributes to its power consumption.

We propose a "green streaming" mode in players, which recommends how much energy can be saved by lowering the quality

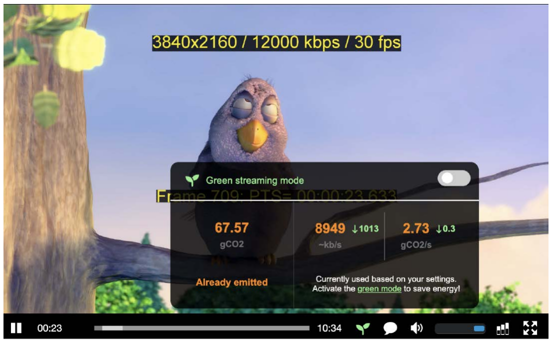

Figure 1: Prototype of green mode turned off

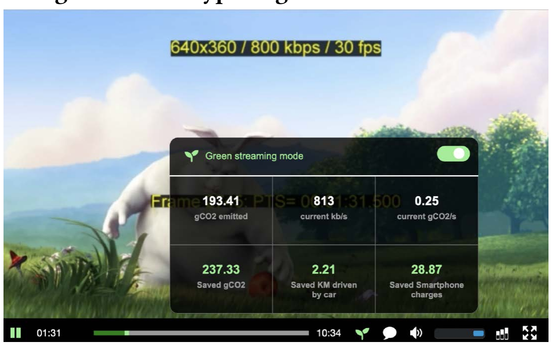

Figure 2: Prototype of green mode turned on

or brightness of the device while maintaining a good viewer experience. This brings energy awareness to customers and can be further improved by providing an incentive to save energy. While it is clear this comes with quality loss, which contradicts a content provider's goal of providing a good QoE to the viewers, the question is how much viewers are willing to compromise for a good cause. User studies to confirm this theory are planned for the future. On a technical level, device-specific QoE measurements are important, e.g. high resolution is important for big screens but might not be necessary for small mobile devices.

As a result, we developed a video player prototype implementing a green streaming mode. The video player prototype is based on dash.js for Web browsers. In the player, the green streaming mode popup displays an approximation of the currently caused CO2 equivalence emissions (Fig. 1). It educates the user about their footprint and offers to reduce the video quality up to a threshold where the users' perceived quality of experience should still be fine, while causing fewer emissions (Fig. 2). The gCo2 emission is calculated based on a simplified formula from [10], where:

> Current emissions in gCO2/s = calculated bitrate in Gb/s * total energy usage in kWh/GB * energy intensity country in gCO2/kWh

From the saved gCO2 we calculated the "Saved KM driven" [2] and "Saved smartphone charges" [3] with the following formulas:

> Saved KM driven = saved gCo2 / 107.5
>
> Saved smartphone charges = saved gCo2 / 8.22

4 ENERGY-AWARE CONTENT STEERING

The idea of energy-aware content steering is based on latest additions to HLS [6] and DASH[1] specifications to enable multi-CDN content steering. This provides players with a standardized fallback mechanism in cases of data center outages or overload. The player parses the steering manifest and chooses the declared delivery path. Content providers typically base their CDN switching decisions based on streaming analytics [7] data from players. Derived QoE metrics such as average bitrate level, warning/error rate or the throughput on a given CDN are used to identify issues. As a result, the order of the CDNs in the steering manifests can be changed dynamically to steer players to a different CDN. Additional factors can be efficiency and cost. However, content providers can also decide on the order of data centers based on their preferences of energy efficency (how the CDN data centers are powered). A content provider could decide on green delivery paths (e.g., prefer data centers powered by sustainable energy over others). This data is dynamically changing due to weather conditions (e.g. wind, sun, temperatures) in different data center locations. Early research to enhance data centers with software-defined energy virtualization layer that provides applications visibility into, and control of, their own energy and carbon usage has been published by Akamai [9]. As of this writing we are not aware of such APIs available in production. As part of our testbed we use simulated data to imitate differently powered data centers. This data is dynamically aggregated with QoE metrics to decide on the order of CDNs in the content steering manifests. End users do not notice a switch to a different CDN, as the switching can be accomplished seamlessly based on the latest additions to HLS and DASH.

5 CONCLUSION

Innovative solutions to improve energy and resource efficiency in the production, processing, distribution and use of digital media will boost the competitiveness of streaming solutions on a global scale. This results in sustainable, ecological and demonstrably energy-efficient media technologies creating positive effects for the entire media industry and spill-over effects in the form of socio-political awareness for consciously sustainable video streaming among users as well as direct economic advantages for market launches of new products and solutions. In conclusion, we have presented a comprehensive study of green streaming technologies, which can significantly reduce the energy consumption and carbon emissions of video streaming services. We have demonstrated the technical feasibility and benefits of context-aware encoding, green media players, and energy-aware content steering. We have also discussed the economic implications and opportunities of these technologies for the streaming industry. Our work contributes to the development and adoption of green streaming solutions, which can help mitigate the environmental impact of online video consumption and support the global goals for sustainability.

REFERENCES

[1] DASH-IF. 2022. *DASH-IF Candidate Technical Specification: Content Steering for DASH.* Retrieved March 27, 2013 from https://dashif.org/docs/DASH-IF-CTS-00XX-Content-Steering-Community-Review.pdf
[2] eea. 2022. *CO2 performance of new passenger cars in Europe.* Retrieved April 26, 2023 from https://www.eea.europa.eu/ims/co2-performance-of-new-passenger

[3] epa. 2022. *Greenhouse Gases Equivalencies Calculator - Calculations and References*. Retrieved April 26, 2023 from https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references

[4] Sarah Griffiths. 2020. *Why your internet habits are not as clean as you think*. Retrieved March 27, 2013 from https://www.bbc.com/future/article/20200305-why-your-internet-habits-are-not-as-clean-as-you-think

[5] George Kamiya. 2020. *The carbon footprint of streaming video: fact-checking the headlines*. Retrieved March 27, 2013 from https://www.iea.org/commentaries/the-carbon-footprint-of-streaming-video-fact-checking-the-headlines

[6] Roger Pantos. 2022. *HTTP Live Streaming 2nd Edition*. Retrieved March 27, 2013 from https://datatracker.ietf.org/doc/draft-pantos-hls-rfc8216bis/

[7] Stefan Pham, Mariana Avelino, Daniel Silhavy, Troung-Sinh An, and Stefan Arbanowski. 2021. Standards-Based Streaming Analytics and Its Visualization. In *Proceedings of the 12th ACM Multimedia Systems Conference* (Istanbul, Turkey) *(MMSys '21)*. Association for Computing Machinery, New York, NY, USA, 350–355. https://doi.org/10.1145/3458305.3478438

[8] Robert Seeliger, Christoph Müller, and Stefan Arbanowski. 2022. Green streaming through utilization of AI-based content aware encoding. In *2022 IEEE International Conference on Internet of Things and Intelligence Systems (IoTaIS)*. 43–49. https://doi.org/10.1109/IoTaIS56727.2022.9975919

[9] Ramesh Sitaraman. 2022. *Carbon First: Rethinking System Architectures for Sustainable Video Streaming: Annual Summit Keynote*. Retrieved March 27, 2013 from https://www.greeningofstreaming.org/post/carbon-first-rethinking-system-architectures-for-sustainable-video-streaming-annual-summit-keynote

[10] sustainablewebdesign.org. 2023. *Calculating Digital Emissions*. Retrieved April 26, 2023 from https://sustainablewebdesign.org/calculating-digital-emissions/