Trade-Offs for Video-Providers in LTE Networks: Smartphone Energy Consumption Vs Wasted Traffic

Christian Schwartz, Marc Scheib, Tobias Hoßfeld, Phuoc Tran-Gia
University of Würzburg
Institute of Computer Science
Würzburg, Germany

Jose Manuel Gimenez-Guzman
Dept. Automática
Universidad de Alcalá
Madrid, Spain

***Abstract*—Long Term Evolution (LTE) networks provide broadband Internet access to mobile users. One of the main use cases for LTE is a mobile video. When selecting a video transmission mechanism, a video provider has to consider different and orthogonal metrics. The consumer expects a high video Quality of Experience (QoE) and a low energy consumption during download and playback. The video provider is interested in minimizing its resources and corresponding costs, like bandwidth and wasted traffic. Wasted traffic occurs if a user aborts and additional video data is already downloaded but not played out, consuming resources unnecessarily.**

This raises the questions 1) how a video provider delivers the video contents while reducing the operational costs and satisfying the customers demands 2) what is the influence of the customer abort behaviour.

To answer these questions, we first study the influence of mechanism selection on energy consumption and wasted traffic. Second, we show that the different user models do not influence the wasted traffic significantly. Finally, we provide parameter selection guidelines for the *Streaming* mechanism, which are shown to satisfy better both the requirements of the video provider as well as those of the customer, to achieve Pareto optimal results with regard to the smartphone energy consumption and wasted traffic.

I. Introduction

In the current mobile Internet, the majority of traffic is caused by video transmissions. By 2017, this value is expected to rise to two thirds of all mobile traffic [1]. Furthermore, the deployment of LTE is expected to rise from 0.1% to 10% in the same timespan according to the same study.

One important factor for successful business considered by video platform operators is the QoE, i.e. the quality of service as perceived by the user. There are several QoE factors like video interruptions, referred to as stalling, but also energy consumption of the smart phone. The video QoE of a user is negatively impacted if video playback stalls, for example because not enough content has been downloaded yet. A high energy consumption results in lower battery lifetime, which frustrates users due to frequent required recharges. Another factor to consider is that if the user stops the playback of the video before completion, from the perspective of the platform operator all content downloaded but not yet watched is lost.

This work was partly funded by the Deutsche Forschungsgemeinschaft (DFG) under Grants HO 4770/1-1, TR257/31-1, and in the framework of the EU ICT Project SmartenIT (FP7-2012-ICT-317846). The authors alone are responsible for the content.

Thus, when evaluating a video transmission mechanism the video QoE, energy consumption of the User Equipment (UE) and wasted traffic should be considered. The contribution of this article is the following. We evaluate four video delivery mechanisms with regard to the three identified metrics. In order to evaluate the amount of wasted traffic, three user models are introduced which specify the probability of a user stopping the video at any point in time. We identify the *Streaming* transmission mechanism as providing good results for all metrics. Then, we perform a parameter study for the buffer threshold and size of the *Streaming* mechanism, in order to allow a network operator to select Pareto optimal configurations according to a trade-off between wasted traffic and energy consumption while only considering parameter sets resulting in maximum QoE, i.e. those preventing all video stalling.

This paper is structured as follows. In Sec. II we give an overview of related work on video transmission in LTE networks. Section III discusses model assumptions, introduces the video transmission mechanisms, and presents the LTE energy model. Furthermore, the metrics used in the remainder of the paper are defined. In Sec. IV we evaluate the discussed mechanisms using deterministic discrete event simulation. We study the impact of selected mechanism on energy consumption, wasted traffic, and provide a trade-off analysis for the *Streaming* mechanism. Finally, we conclude in Sec. V.

II. Background and Related Work

In order to match the demand of video transmission over the Internet, multiple solutions exist [2]. The most basic approach, *Download*, obtains the complete video at once, playing back any available content as required. Due to the nature of *Live* video transmissions it is only possible to send the currently available content. Furthermore, introducing delay into the livestream should be avoided as it reduces the timeliness of the video. There exist different approaches for *Streaming* video content to a user. In server based solutions, the streaming server controls the transmission of content. One example of such a server based approach is the Real Time Streaming Protocol (RTSP) which was widely discussed as a standardized solution for mobile video streaming [3].

In the more recent past, client based approaches were discussed. Here the client controls the download and playback of

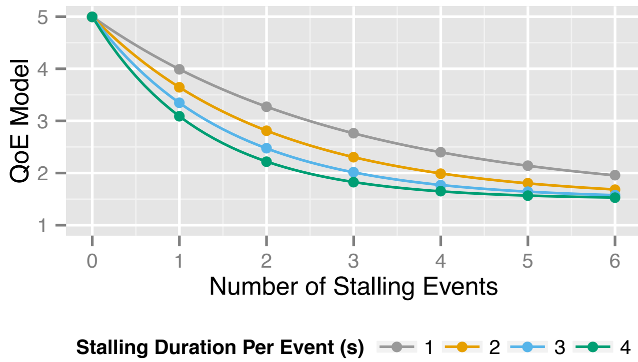

Fig. 1: Influence of Number of Stalling Events and Stalling Length on QoE [9]

content. The authors of [4] study the QoE of HTTP Adaptive Streaming (HAS) approaches, if the content is consumed via LTE networks. They highlight the differences to existing server-side approaches and suggest the study of cross-layer optimization approaches in order to improve the QoE. One approach to deliver HAS is MPEG-DASH, which enables video streaming over HTTP [5]. Considering both the video content as well as the available resources by using a proxy has been suggested to improve the users QoE [6]. In [7] the authors suggest the use of a caching strategy, downloading video content according to a user viewing history and network conditions.

The authors of [8] perform a measurement of power consumption and Radio Access Network (RAN) signalling during playback of a *YouTube* video. They employ a proxy server in order to ensure that traffic is sent in bursts, thus decreasing power consumption at the cost of additional signalling traffic.

III. Model

In this section we first describe our model assumptions. Then we introduce a model for the video transmission mechanisms considered. Finally, we present a power and Radio Resource Control (RRC) model for an LTE UE.

A. Model Assumptions

Maintaining a high QoE for their viewers is an important goal for operators of video platforms. The authors of [9] found that the QoE is mainly influenced by the number of stalling events and the stalling event duration. As shown in Fig. 1, the QoE model, where 5 is the highest possible QoE and 1 the lowest, rapidly decreases if the number or duration of stalling events increases. The provided QoE model between stalling and QoE shows that stalling significantly worsens QoE. Thus, an operator has to avoid stalling at any case. As a consequence, in this paper, we only consider scenarios where no stalling occur, i.e. the delivery bandwidth is larger than the video bitrate to ensure a smooth video playout. Otherwise, the operator will use QoE management approaches to overcome resource limitations, e.g. by reducing the application requirements with DASH/SVC [10] or by prebuffering data [11].

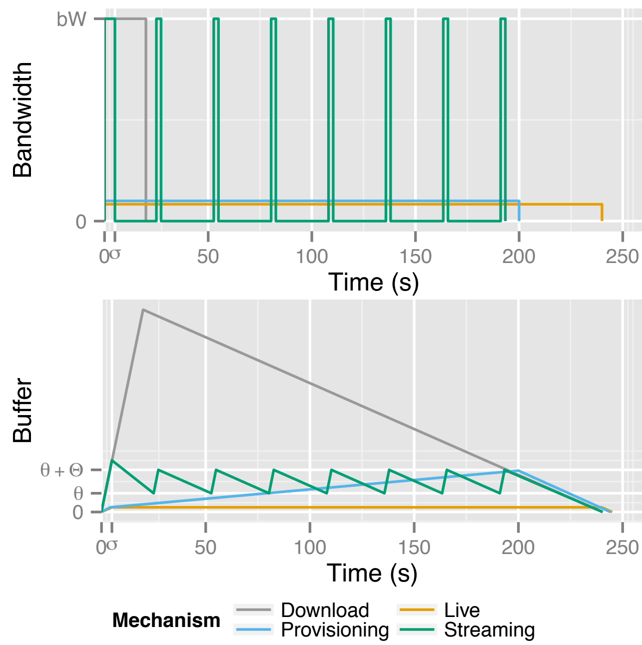

Fig. 2: Behaviour of Transmission Mechanisms. Different Playback End Times Due to Different Playback Starts

Furthermore, we assume that all videos are played back with a constant bitrate b_R. Thus, each second of the video, independently of its content, requires the same number of bits.

We consider video transmission between a server and a user equipped with an LTE enabled smartphone. The available bandwidth of a UE depends on many factors, such as location, number of users in the cell, activity of other users, and line of sight. To simplify the evaluation scenarios we assume that a constant maximum bandwidth b_W is provided to the user. We assume that the bottleneck of the connection is the air interface, thus the full bandwidth b_W available is used for the video download. We consider scenarios where the available bandwidth of the UE is higher than the video bitrate in order to prevent stalling. Although the assumptions of constant bitrate and bandwidth do not hold in a real environment, the purpose of considering such assumptions is twofold. First, they are useful to know the performance of the discussed mechanisms in optimal conditions without any other effects that could disturb the results and, second, they serve as a baseline for comparison with fitted random variables for both bandwidth and bitrate as discussed in Sec. V.

B. Video Traffic Model

In our study we focus on four transmission mechanisms which are currently in use. Fig. 2 shows the consumed bandwidth and the available seconds of video for playback for a video watched for all considered transmission mechanisms. For each point in time t the amount of video in seconds already played back is given as $t_p(t)$.

The *Download* mechanism can be used if a user wants to watch a pre-encoded video. Thus, the complete video is ready

Symbol	Full Name	Measured Value
T_{ON}	RRC Connected *On* duration timer	1 ms
T_{I}	DRX inactivity timer	100 ms
T_{S}	Short DRX duration timer	20 ms
T_{L}	Long DRX duration timer	40 ms
$T_{\texttt{Idle}}$	RRC Connected timeout	11.576 s
$T_{\text{ON}}^{\texttt{Idle}}$	RRC Idle *On* duration timer	43 ms
$T_{\text{DRX}}^{\texttt{Idle}}$	RRC Idle DRX duration timer	1.28 s
D_P	Promotion Delay	260 ms

TABLE I: RRC and DRX Parameters [16]

to be transmitted as soon as the user starts the transmission. The required time of the download is only bounded by the bandwidth available in the network.

Video watched during *Live* transmissions is encoded as it is recorded. Thus, the bandwidth used to transmit the video is always limited to the video bitrate b_R.

In [12] the authors show the influence of the video demand, i.e. the ratio of available bandwidth and required video bandwidth, on the stalling frequency. In order to reduce stalling, the bandwidth used to download the video should be provisioned so that the available bandwidth exceeds the video bandwidth by a high enough factor. In the *Provisioning* mechanism, the download bandwidth is chosen so no stalling occurs. In order to reduce stalling and improve the QoE of a video, the available bandwidth should be at least 120 % of the video bitrate b_R [13].

For the *Streaming* mechanism the complete video is encoded in advance, allowing for the full bandwidth of the UE being used for download. The video is downloaded with full bandwidth for a *prebuffering time* σ in order to guarantee a stalling-free start of the playback. After σ seconds the download stops and the playback begins. The download is only resumed if the available seconds of video for playback are below a *stop threshold* θ. The download continues until the buffer contains a *threshold size* Θ, resulting in a total buffer length of $\theta + \Theta$ s. This is repeated until the download is completed.

A video provider will also consider its bandwidth to be a resource to be conserved. However, when comparing the bandwidth available in LTE with that of a wired network, we can assume the air interface to be the bottleneck. Furthermore, not considering bandwidth as an optimization target of the video provider simplifies the study as it removes one additional metric.

C. LTE Network Model

In order to quantify the energy consumption during wireless transmission, we model the LTE RRC behaviour defined in [14]. To reduce the energy consumption, the concept of Discontinious Reception (DRX) has been introduced in [15]. The authors of [16] provide measurements of important RRC and DRX parameters which are used in the following model and are reproduced in Tab. I.

The RRC protocol for LTE consists of two states, as shown in Fig. 3. In RRC Idle state, the UE is in DRX mode. Here, the UE monitors the Physical Downlink Control Channel

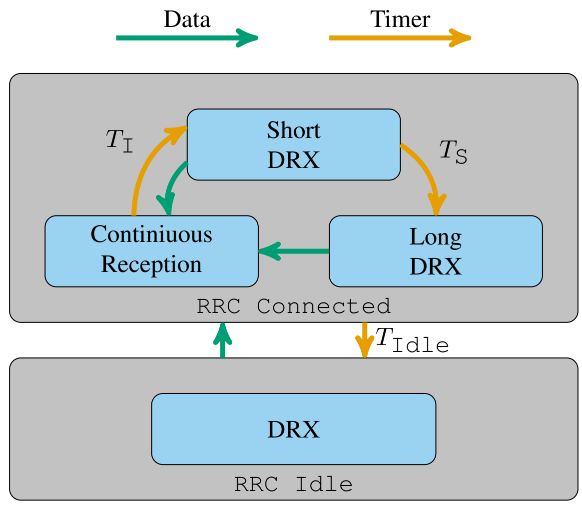

Fig. 3: LTE RRC Model

(PDCCH) for $T_{\text{ON}}^{\texttt{Idle}}$ in each DRX interval of duration $T_{\text{DRX}}^{\texttt{Idle}}$. The time of a promotion to the RRC Connected state is given by the promotion delay D_P and occurs as soon as a packet is sent or received. If a packet is sent or received while in RRC Connected, including the initial packet which triggered the promotion to RRC Connected, the timers T_{I} and $T_{\texttt{Idle}}$ are started. Until the T_{I} timer expires, the UE is in Continuous Reception (CRX) mode. After the $T_{\texttt{Idle}}$ timer expires, the UE demotes to RRC Idle. Upon expiration of the T_{I} timer, the UE enters Short DRX. Here, the T_{S} timer is started and the UE monitors PDCCH for T_{ON}. If a packet is sent or received while in Short DRX, CRX begins and the T_{S} timer is disabled. Once the T_{S} timer expires, Long DRX is entered and T_{L} is started, again the UE monitors PDCCH for T_{ON}. This is repeated until a packet is sent or received and the CRX state is entered or until the $T_{\texttt{Idle}}$ timer expires and RRC Idle is entered.

We give the download bandwidth at any time t as $b_d(t)$. Furthermore, we denote the length of the video already downloaded at any time t as

$$t_d(t) = \frac{1}{b_R} \int_{\tau=0}^{t} b_d(\tau) d\tau. \tag{1}$$

D. Evaluation Metrics for Smartphone Energy Consumption and Wasted Traffic

We calculate the *energy consumption* of the UE due to wireless transmission at any given moment using the UE's current state and the bandwidth in use. We only consider the energy consumption due to wireless transmission, as it is an offset to the energy consumption caused by the playback of the video. The video playback itself is unaffected by the choice of transmission mechanism. Thus the selected transmission mechanism only influences the energy consumption of the wireless transmission. In [16] the authors provided measurements for the energy consumption of each state (see Tab. II) if

Description	Paper
`RRC Idle` (base)	11.4 mW
DRX during `RRC Idle`	594.3 mW
Promotion	1210.7 mW
`RRC Connected` (base)	1060.0 mW
DRX during `Short DRX`	1680.2 mW
DRX during `Long DRX`	1680.1 mW
α	51.97 mW/Mbit/s
β	1288.04 mW

TABLE II: Power Consumption Per System State [16]

the UE is receiving no data. Furthermore, an approximation of the power consumption at time t if a download occurs is given as $P(t) = \alpha \cdot b_d(t) + \beta$. In order to compute the overall energy consumption E during the transmission and playback of the video, we add the power consumed in each state in which the UE is not receiving and the power consumed during receiving while considering the used bandwidth at each moment.

If a user stops watching a video currently being downloaded before its end, this leads to *wasted traffic*, a metric that impacts the video provider, but is influenced by the user aborting the video. Because this decision can not be influenced by the video provider, a user model has to be assumed by the video provider in order to provide a performance analysis of the different video delivery mechanisms.

Considering that transmitting data to a smartphone costs both money and traffic, a transmission mechanism should attempt to reduce the amount of video which has been transmitted but is not yet watched at any time t as $t_u(t) = t_d(t) - t_p(t)$. If the user stops the playback according to a random variable A with Probability Density Function (PDF) a, we can give the wasted traffic W as the expected value of t_u under A.

$$W = E\left[t_u\right] = \int_{t=0}^{\infty} a(t) t_u(t) dt. \quad (2)$$

High values of W indicate that server and network resources are used for traffic which is not watched by the user.

We consider three types of user behaviour, each modeled by a random variable describing the abort time, i.e. the time when the user stops watching a video. First we consider a *uniform* distributed user abort model, where the user can abort the video at any time. Due to the uniform distribution of the abort time and the length of the video, that is 1600 seconds (≈27 minutes), the mean time of stop occurs at 800 seconds (≈13 minutes). Second, we consider a type of user that watches a part of the video before deciding if he or she should stop watching. After the main part of the video has been watched, the user is again more likely to abort. To model this kind of behaviour we use a *truncated normal distribution* over the playtime of the video, assuming a symmetry of the abort density at the half-way point of the video. We use the same mean and specify a standard deviation of 400 seconds (≈7 minutes). Third and finally, we assume that the user is more likely to abort the video at the beginning. We model this user behaviour using a *truncated lognormal distribution* with the same mean and a standard deviation of 0.8 seconds for the normal distribution at the basis of the lognormal distribution.

Note that the wasted traffic W is influenced by the user abort model because wasted traffic only occurs if a user aborts a video. Even though this may only affect a subset of all watched videos, it still consumes unnecessary resources and should be considered by the video provider. However, the download of videos always consumes energy and the largest amount of energy is consumed if the user does not abort the video. Thus, we optimize for the worst case energy consumption. Any other optimization target would offer incentives to users to abort watching the video early, resulting in additional wasted traffic for the provider.

IV. Numerical Evaluation

In this section we provide answers for the questions outlined in the abstract of this paper.

1) In Sec. IV-A and Sec. IV-B we study the impact of the considered transmission mechanisms. We find that the *Streaming* mechanism provides acceptable results for both metrics. In Sec. IV-C we evaluate the impact of parameter choices for the *stop threshold* θ and the *threshold size* Θ.
2) In Sec. IV-B we consider the influence of user behaviour on wasted traffic by evaluating different user models.

We consider a video of about 27 minutes ($l = 1600$ s) length which is viewed on a UE with LTE access. The median of available downlink throughput in current LTE networks is $b_W = 12.74 \ Mbit/s$ [16]. A wide set of video bitrates between 1 and 50 $Mbit/s$ is in use [17]. In order to prevent stalling, we consider bitrates between 1 and 10 $Mbit/s$, staying below the available network bandwidth. For the *Streaming* mechanism, thresholds of $\theta = 4$ s and $\Theta = 32$ s were selected. Furthermore, we specify a prebuffering duration of $\sigma = 5$ s. The influence of different threshold settings will be studied in Sec. IV-C.

We conduct our study using deterministic discrete event simulation which uses no random variables. The wasted traffic is obtained analytically using the abort behaviour model. Thus, all results are exact under the previously stated assumptions.

A. Energy Consumption

First, we study the influence of both video bitrate as well as the selected download mechanism on energy consumption in Fig. 4. We consider the *Download* mechanism and observe that it consumes the least amount of energy. Here the video is downloaded with full bandwidth, as seen in Fig. 2, resulting in a very short energy intensive download phase and a longer energy un-intensive playback phase. For the *Live* mechanism we observe the opposite, i.e. the highest energy consumption for all bandwidths. If this mechanism is used, the used bandwidth equals the video bitrate. Thus, the download requires the same amount of time as the playback, resulting in the highest possible energy consumption. The *Provisioning* method uses a higher bandwidth, thus reducing the overall download time. This reduced download time decreases the energy consumption when compared to the *Live* mechanism, even though the bandwidth used for downloading is increased to 120%. For

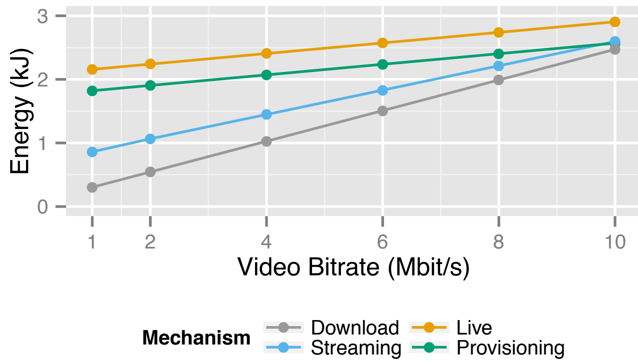

Fig. 4: Influence of Bitrate and Download Mechanism on Energy Consumption

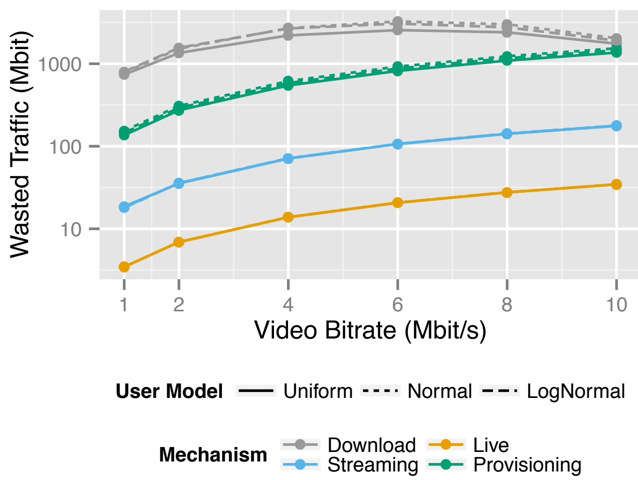

Fig. 5: Influence of Bitrate, Download Mechanism and User Model on Wasted Traffic

the *Streaming* mechanism we observe an energy consumption slightly higher than the *Download* mechanism. As the bitrate of the video increases, the energy consumption increases as well. This is due to the fact that a higher video bitrates require larger downloads. For video bitrates approaching the available bandwidth the *Streaming* mechanism degenerates to the *Live* mechanism, as no prebuffering is possible. We conclude that the *Download* and *Streaming* mechanisms outperform *Live* and *Provisioning* with regard to energy consumption.

B. Wasted Traffic

Next, we consider the wasted traffic as a metric of the transmission mechanism quality. If a user completely watches a video, no traffic is wasted. Thus, we consider only the cases where a user stops the playback before the video is finished. In Fig. 5 we study the wasted traffic for different video bitrates. We consider the different download mechanisms introduced in Sec. III-B as well as the previously introduced user models. We observe that the choice of user model has no significant impact on the wasted traffic. For the *Download* mechanism, the amount of wasted traffic increases up to a video bitrate of $6\,Mbit/s$, then the wasted traffic decreases because only video data which has been prebuffered can be lost if the user aborts the video. As we assume a available bandwidth of $12.74\,Mbit/s$, the bandwidth available for prebuffering decreases as the bitrate increases, resulting in lower amounts of wasted traffic for high video bitrates. For the *Live* mechanism, we see that the wasted traffic for all user models is very low, but wasted traffic exists. This is due to the traffic already sent by the server while the UE is still waiting for promotion from `RRC Idle` to `RRC Connected`, i.e. a short prebuffering phase exists. As the bandwidth increases with the video bitrate, the wasted traffic increases as well. Next, we consider the *Provisioning* approach and see an increase of wasted traffic as the video bitrate increases because the bandwidth used for continuous download is a factor of the video bitrate. A higher video bitrate results in the download of the video being completed earlier, which leads to more wasted traffic. Similar results can be seen for the *Streaming* mechanism, which results in more wasted traffic than the *Live* mechanism, but significantly less traffic than the *Provisioning* mechanism. This is due to the fact that if the user aborts, at least the amount of video given by the *stop threshold* θ and at most the complete buffer, given by the *stop threshold* and the *threshold size* are lost. We have observed that the choice of user model results in no qualitative changes in wasted traffic. As we have seen, the *Download* and *Streaming* mechanisms provide best results with regard to energy consumption. However with regard to wasted traffic, the *Live* and *Streaming* mechanisms are most suited. Thus, the *Streaming* mechanism seems to be a good compromise. The network operator can select a trade-off between energy consumption and wasted traffic as discussed in the next section. From now on, we only consider the uniformly distributed user model and the *Streaming* mechanism.

C. Influence of Buffer Threshold Selection

In this section, we discuss the influence of the lower buffer threshold θ and the buffer size Θ on both the energy consumption P and the wasted traffic W for a uniformly distributed user model as shown in Fig. 6. Considered stop thresholds are in the range of 4 to 32 seconds. Lower stop threshold values result in stalling, as the buffer runs empty while the UE is still waiting for the promotion delay to be completed and sufficient amount of data to be downloaded to continue playback. For sake of readability, we show only the video bitrates 2, 6, and $10\,Mbit/s$ and show the Pareto frontier, i.e. the set of all parameter combinations where no other parameter combination yields better results for both metrics, of evaluated parameters as a connected line.

We observe that, independent of video bitrate, the values found on the Pareto frontier can be obtained for the smallest considered buffer threshold. Increasing the buffer size decreases the energy consumption at the cost of a higher wasted traffic. Choosing a small lower buffer threshold θ decreases the minimum amount of wasted traffic if the user stops watching a video. Selecting a higher buffer size Θ increases the wasted traffic, as more video can be downloaded and thus wasted if

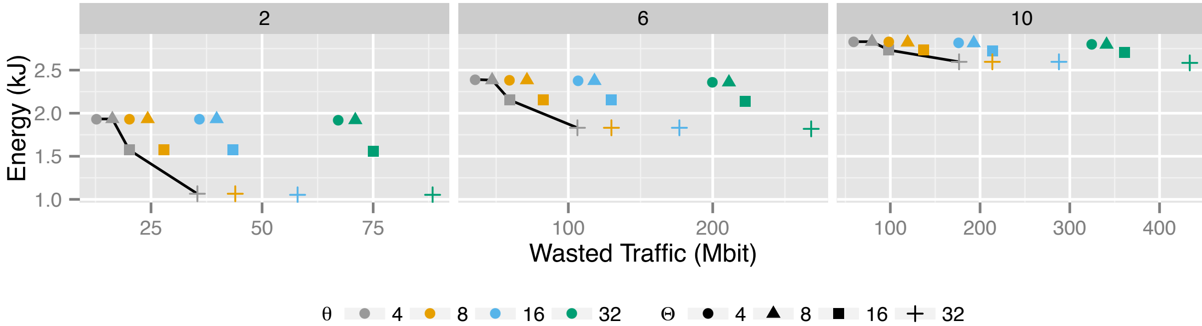

Fig. 6: Energy Consumption and Wasted Traffic for Varying Video Bitrates for the Streaming Mechanism

a user stops watching the video. Increasing the buffer size Θ decreases the energy consumption, because a longer buffer size allows for the video to be downloaded in fewer bursts and each of them is followed by the $T_{\mathtt{Idle}}$ timeout where the UE is still in the most energy intensive `RRC Connected` state.

For the *Streaming* mechanism, we recommend to always use the smallest possible stop threshold generating no stalling. The choice of the buffer size depends on the selected trade-off between energy consumption and wasted bandwidth, with smaller threshold sizes requiring more energy and higher threshold sizes causing a higher wasted traffic. Video providers should evaluate the power and wasted traffic metrics per video, considering video size and variable video bitrate information whose impact will be studied in future work.

V. Conclusion

We compared the difference in energy consumption and wasted traffic for different video transfer mechanisms. Due assumptions of constant video bitrate and available bandwidth, we give exact results for consumed energy and the wasted traffic if a user aborts the video according to different models.

First, we show that the user model has no significant impact on wasted data. Furthermore, we observe that among all considered mechanisms, the *Streaming* mechanism offers the best trade-off between energy consumption and wasted data. Finally, we show that the *Streaming* mechanism is optimal if the smallest lower buffer threshold θ causing no stalling is selected. The *Streaming* mechanism can be tailored to specific needs by manipulating the download buffer size Θ, allowing for a trade-off between energy consumption and wasted traffic.

Video providers can decrease resource consumption in their data centers and increase customer satisfaction by securing a low power consumption due to video traffic and a high video QoE by selecting appropriate video transmission mechanisms and parameters. We are currently extending our simulation framework to support bandwidths modeled using fitted random variables, variable video bitrates based on a representative set of *YouTube* videos and video QoE as an additional optimization metric. Video providers will be able to use this tool to select appropriate parameters in real-time, depending on video and network properties, optimizing energy consumption, wasted traffic and video QoE.

References

[1] Cisco, "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012-2017," White Paper, Feb. 2012.

[2] A. Begen, T. Akgul, and M. Baugher, "Watching Video Over the Web: Part 2: Applications, Standardization, and Open Issues," *Internet Computing*, vol. 15, no. 3, 2011.

[3] I. Elsen, F. Hartung, U. Horn, M. Kampmann, and L. Peters, "Streaming technology in 3G mobile communication systems," *Computer*, vol. 34, no. 9, 2001.

[4] O. Oyman and S. Singh, "Quality of Experience for HTTP Adaptive Streaming Services," *Communications Magazine*, vol. 50, no. 4, 2012.

[5] I. Sodagar, "The MPEG-DASH Standard for Multimedia Streaming Over the Internet," *MultiMedia*, vol. 18, no. 4, 2011.

[6] A. E. Essaili, D. Schroeder, D. Staehle, M. Shehada, W. Kellerer, and E. Steinbach, "Quality-of-Experience driven Adaptive HTTP Media Delivery," in *International Conference on Communications*, Jun. 2013.

[7] X. Li, M. Dong, Z. Ma, and F. C. Fernandes, "Greentube: power optimization for mobile videostreaming via dynamic cache management," in *Conference on Multimedia*. ACM, 2012.

[8] M. Siekkinen, M. Ashraful, J. K. N. Hoque, and M. Aalto, "Streaming over 3G and LTE: How to Save Smartphone Energy in Radio Access Network-Friendly Way," in *Workshop on Mobile Video*, Feb. 2013.

[9] T. Hoßfeld, R. Schatz, E. Biersack, and L. Plissonneau, "Internet Video Delivery in YouTube: From Traffic Measurements to Quality of Experience," in *Data Traffic Monitoring and Analysis: From measurement, classification and anomaly detection to Quality of experience*. Springer's Computer Communications and Networks series, 2012.

[10] T. Hoßfeld, F. Liers, R. Schatz, B. Staehle, D. Staehle, T. Volkert, and F. Wamser, "Quality of Experience Management for YouTube: Clouds, FoG and the AquareYoum," *PIK - Praxis der Informationverarbeitung und -kommunikation*, Aug. 2012.

[11] C. Sieber, T. Hoßfeld, T. Zinner, P. Tran-Gia, and C. Timmerer, "Implementation and User-centric Comparison of a Novel Adaptation Logic for DASH with SVC," in *International Workshop on Quality of Experience Centric Management*, Ghent, Belgium, May 2013.

[12] T. Hoßfeld, T. Zinner, R. Schatz, M. Seufert, and P. Tran-Gia, "Transport Protocol Influences on YouTube QoE ," University of Würzburg, Tech. Rep. 482, Jul. 2011.

[13] T. Hoßfeld, D. Strohmeier, A. Raake, and R. Schatz, "Pippi Longstocking Calculus for Temporal Stimuli Pattern on YouTube QoE," in *Workshop on Mobile Video*, Feb. 2013.

[14] *TS 25.331, Radio Resource Control (RRC); Protocol specification*, 3GPP Std., 2012.

[15] *TS 36.321, Evolved Universal Terrestrial Radio Access (E-UTRA); Medium Access Control (MAC) protocol specification*, 3GPP Std., 2013.

[16] J. Huang, F. Qian, A. Gerber, Z. M. Mao, S. Sen, and O. Spatscheck, "A Close Examination of Performance and Power Characteristics of 4G LTE Networks," in *Conference on Mobile Systems, Applications, and Services*, 2012.

[17] YouTube, "Advanced encoding settings – Recommended bitrates, codecs, and resolutions, and more," 2013. [Online]. Available: http://support.google.com/youtube/bin/answer.py?hl=en&hlrm=de&answer=1722171