# Energy-efficient and QoE-driven adaptive HTTP streaming over LTE

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***Abstract*—LTE networks offer broadband wireless access to mobile users who can benefit from high data rate applications such as video streaming. In order to improve the user satisfaction, Quality-of-Experience (QoE) based resource allocation for multiple streaming users in an LTE cell has been studied. However, the high energy consumption of these applications has not been considered. In this paper, we propose adaptive Discontinuous Reception (DRX) parameters for LTE that reduce the energy consumption of mobile devices without degrading the video quality of adaptive HTTP streaming users. Furthermore, we extend the QoE-optimized resource allocation by additionally considering the power consumption of the mobile devices. Simulation results show the benefits of using the proposed adaptive DRX parameters and that further energy saving gains can be achieved by including the power consumption in the optimization problem.**

## I. Introduction

Emerging 4G broadband wireless technologies such as 3GPP Long Term Evolution (LTE) and enhanced capabilities of devices like smartphones and tablets have boosted multimedia services such as mobile TV and video-on-demand over the mobile networks. Currently, video traffic is approximately 50% of the overall traffic and by 2018, more than 60% of the world's mobile data traffic will be video, according to estimates [1]. This massive increase in mobile video traffic challenges the mobile network operators, which have to allocate the scarce network resources among multiple clients while maximizing the user Quality-of-Experience (QoE).

Furthermore, the high data rates of video streaming drain the battery of the User Equipment (UE) very quickly. To improve the battery life of the UE, LTE introduces Discontinuous Reception (DRX) mechanisms [2], [3] that allow the UE to go to sleep mode and turn off its circuitry when it is not actively transmitting or receiving any data. With DRX, small pauses between transmission bursts can be exploited to save the UE's energy by micro sleep operations even when the UE is active and streaming a video. However, DRX saves energy at the cost of small delays which can decrease the average throughput and hence degrade video quality. Therefore, DRX parameters need to be carefully configured if certain quality constraints have to be fulfilled during a video streaming session.

Nowadays, most of the video streaming is based on HTTP/TCP [1]. Especially, the new paradigm of adaptive HTTP streaming (e.g. recently standardized MPEG Dynamic Adaptive HTTP streaming (DASH) [4]) enables video clients to adapt to varying transmission rates as is the case in mobile networks with limited and fluctuating resource availability. In adaptive HTTP streaming over mobile networks, the client decides on the application (video) data rate based on its observed throughput and an internal rate control algorithm, whereas the network operator decides on the resource allocation at the base station. In our previous work [5], an approach is presented where the mobile network operator decides on both the resource share and the video data rates of multiple users in order to maximize the overall QoE. The QoE optimization is based on the channel conditions and the video characteristics of all users. A proxy in the network is used to rewrite the clients' HTTP requests which makes the approach applicable to any adaptive HTTP streaming client. However, the UE's energy saving opportunities during a streaming session are not taken into account.

In this paper, we extend the work in [5] by first determining adaptive DRX parameters in order to improve the energy efficiency without degrading the video quality. Unlike fixed DRX, the parameters are chosen according to the transmission constraints and adapted periodically to the varying conditions. Additionally, a new optimization problem which jointly considers QoE and power consumption is proposed where the opposing requirements of energy saving and video quality can be balanced for further energy saving gains. Our simulation results indicate that while the QoE optimization can improve the average MOS by 11% compared to a standard DASH scenario, the mean power of the users can be reduced by 32% by using the proposed DRX parameters.

The rest of the paper is organized as follows. We review related work in the next section. In Section III, we provide background information on adaptive HTTP streaming, QoE optimization and the DRX mode in LTE. We then determine adaptive DRX parameters for adaptive HTTP streaming in Section IV. We describe the UE power model in Section V. The joint energy saving and QoE driven resource allocation is presented in Section VI. Section VII presents our simulation results and Section VIII concludes the paper.

## II. Related Work

Different studies [6], [7] have been conducted to analyze the performance of the DRX mechanism in LTE. However, only few works in literature are related to adaptive DRX mechanism. In [8], an adaptive DRX scheme is proposed where DRX parameters change based on system load and channel variation. The authors in [9] present a DRX-aware scheduling scheme which can provide a certain Quality of Service for internet-of-things applications while reducing energy

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consumption of the UE. [10] points out that power saving by DRX comes at the cost of degraded system utilization. Yet, these works do not consider video streaming and the impact of DRX on video quality. The authors in [11] describe DRX for RTP video streaming but do not consider multi-user resource allocation with DRX mechanism for video streaming.

Meanwhile different approaches have been proposed to enhance the user experience in adaptive HTTP streaming. [12], [13] and [14] describe client-driven algorithms which consider the client's throughput and quality of DASH contents to improve the playback experience. However, these algorithms only look at an individual client without further considering other DASH clients competing for resources in the same network. Authors in [15] and [16] propose schemes to improve the experience of multiple DASH clients sharing the same network resources. These schemes, however, do not take video contents of individual clients into account. Nonetheless, none of these works considers power saving opportunities during QoE optimized adaptive HTTP streaming. To the best of our knowledge, there is no work that addresses how to improve playback experience of multiple DASH clients in a wireless cell along with reducing the energy consumption through adaptive DRX and resource allocation. Hence, this paper presents an approach for adaptive HTTP media delivery to multiple users in a LTE cell, that maximizes the overall experience of all users in the cell in an energy-efficient way.

## III. Background

### A. Dynamic adaptive streaming over HTTP

The major problem with traditional HTTP progressive download is that it is not able to handle the varying transmission conditions of the network, which may result in frequent stallings for limited transmission capacity. To address this issue, the concept of adaptive HTTP streaming and the DASH standard were introduced [17]. The adaptive approach offers intra session rate adaptation and is able to adapt to varying transmission rates. In DASH, a video sequence is divided into small segments and each segment is encoded at multiple bit rates called representations (and thus in different qualities) and stored at the server. A DASH client can seamlessly switch between the different segments during the streaming session by adjusting the streaming rate to its estimated transmission capacity, thus eliminating playout interruptions [18].

### B. QoE-based adaptive HTTP streaming over LTE

The QoE of multiple DASH streaming users can be maximized in a mobile network by allocating the radio resources based on the users' video characteristics and channel conditions. A QoE-based resource optimization system is presented in [5] and depicted in Figure 1. In this system multiple mobile clients are simultaneously streaming different DASH contents in a LTE cell. A QoE optimizer module is implemented at the base station (eNodeB). It periodically collects information about the video characteristics and average channel information of all users to determine the optimum resource share of each user to maximize the overall user satisfaction.

In contrast to classical DASH streaming where the client chooses the video rate of a segment, a proactive approach is proposed where a proxy rewrites the clients' HTTP requests

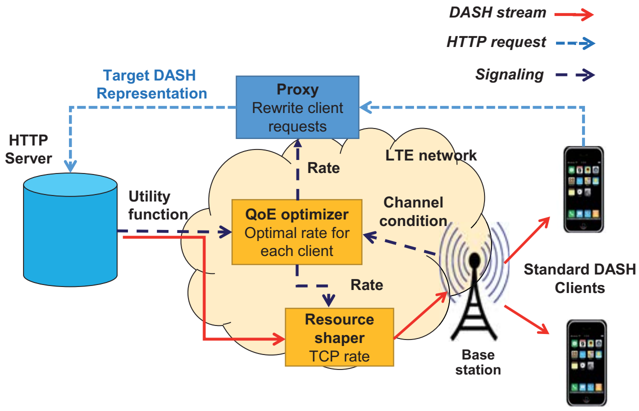



Fig. 1. QoE-Based adaptive HTTP system architecture [5]

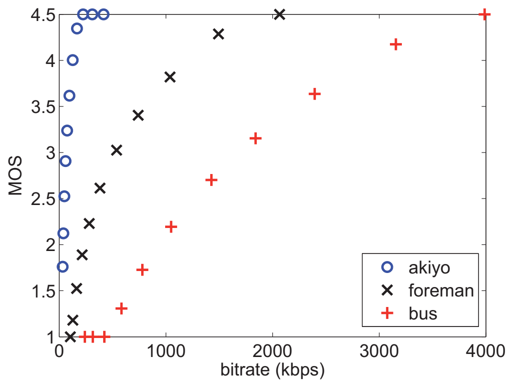



Fig. 2. Example utility functions for 3 different videos.

and a TCP shaper in the network imposes the throughput according to the output of the optimizer. Both DASH client and server ends are unaware of the proposed proxy operation and remain unmodified standard DASH client-server.

The video-dependent utility function $U$ or QoE of user $i$ is expressed on a Mean Opinion Score (MOS) scale [19] as a function of the video rate, $U_i = f_i(R_i)$. MOS can take any value between 1.0 and 4.5 which represent the worst and the best QoE, respectively. Figure 2 shows example utility functions for 3 different videos. The utility information is either known to the optimizer or can be estimated in the network [20].

We consider a long-term radio layer model with optimization cycles in the order of seconds. This allows us to integrate our QoE-based optimization on top of state-of-the-art schedulers for LTE without modifying them. We use the link layer model originally proposed in [21]. It defines the data rate $R_i$ of user $i$ as a function of its resource share $\alpha_i$ and its maximum achievable rate $R_{max,i}$ if all the resources are allocated exclusively to user $i$, cf. (1).

$$R_i = g_i(\alpha_i) = \alpha_i R_{max,i} \quad 0 \leq \alpha_i \leq 1, \forall i \tag{1}$$

In each optimization round, a new $R_{max,i}$ is determined for each UE based on its average channel statistics in the previous second. We use the link layer model from the 3GPP recommendations [22] to determine the achievable throughput for a given mean Signal-to-Noise ratio. The model approximates the throughput in the downlink after link adaptation and hybrid automatic repeat request, by a loss factor of 0.6 compared to the Shannon capacity.

The QoE-based resource optimization function finds the resource share of each user to maximize the overall MOS under the constraint of limited resources. The optimization problem for a number $N$ of clients is formulated as:

$$\arg\max_{(\alpha_1,\ldots,\alpha_N)} \quad \sum_{i=1}^{N} U_i(\alpha_i) \tag{2}$$

$$subject\ to \quad \sum_{i=1}^{N} \alpha_i \leq 1 \tag{3}$$

where (2) determines the resource share of each user so that the overall MOS of all users is maximized. The results in [5] show the enhancement in mean QoE over all users. But video streaming drains the UE battery very quickly and energy saving opportunities during the streaming sessions are not considered in [5].

### C. Discontinuous Reception (DRX) Mechanism in LTE

DRX [2] can be configured in LTE as an effective energy saving mechanism. It allows the UE to turn off its radio interface to save battery when there is no data activity for the UE. Each UE has its own DRX configuration which is determined by the eNodeB.

The basic unit of sleep and wake-up duration of the UE in DRX is a LTE subframe (i.e. 1 ms). When the DRX mechanism is enabled, the UE follows a specific sleep and wake-up pattern as shown in Figure 3. There are six DRX parameters that can be configured for each UE. 1) DRX-inactivity-timer, 2) shortDRX-cycle, 3) On-duration, 4) longDRX-cycle, 5) DRX-shortCycle-timer and 6) DRX-offset. The UE stays in wake-up state and continuously monitors the physical downlink control channel (PDCCH) when the DRX-inactivity-timer ($T_{in}$) is running. Upon a packet arrival at the UE, the $T_{in}$ timer is reset. Once $T_{in}$ expires, the UE enters DRX cycles by starting shortDRX-cycles ($T_{SDC}$). During a DRX cycle, the UE monitors PDCCH for On-duration ($T_{on}$) and remains asleep for the rest of the cycle to save energy. During a UE's sleep period, all data for the UE will be buffered at the eNodeB until the next $T_{on}$ comes. If no data is received during the On-durations of a predefined number of shortDRX-cycles, the UE will make a transition to longDRX-cycles. In a longDRX-cycle, the UE behaves the same as in shortDRX-cycles but can spend more time in sleep mode to save more energy. Once the UE receives a packet, it suspends the DRX cycles and sets $T_{in}$ again.

The DRX configuration saves energy but also affects the packet delay and bit rate. For example, a shorter $T_{SDC}$ will reduce the UE's packet delay but also its sleep period. Similarly, a UE with longer $T_{on}$ can enjoy higher bit rate but consumes more energy. Therefore, how to configure the DRX parameters is a critical problem. Furthermore, DRX parameters can be adaptive and application dependent. Based on the application type, the DRX parameters can be selected such that the energy saving is maximized.

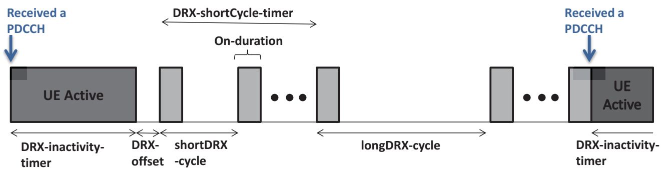



Fig. 3. Overview of LTE DRX [3]

## IV. Proposed adaptive DRX parameters

A fixed DRX configuration can potentially lead to an increase in the packet delay, (e.g. if the sleep cycles are too long), which can affect the user experience. Hence, it is beneficial to adapt the DRX parameters to the current traffic activity of each user. In adaptive DRX mode, the DRX parameters can be modified in real-time to adapt to the ongoing traffic pattern. In the case of DASH streaming, the DRX configuration should be selected such that the UE spends the necessary amount of time in wake-up state in order to download video segments in time and play them without any interruptions and on the other hand avoid unnecessary wake-up time to save energy.

We consider DASH streaming over LTE with the approach illustrated in Figure 1. In downlink transmission, Maximum Transmission Units (i.e. 1500 bytes packets) are coming from the DASH server and passed through the TCP rate shaper to reach the eNodeB with a constant packet rate. The idea is to match the periodic pattern of the DRX cycles with the periodic packet arrivals for each user. A packet is served during the On-duration, and the rest of the time, the UE can go to sleep mode. The parameters are calculated periodically for each optimization cycle and sent to the UEs. Short DRX cycle length, On-duration and DRX inactivity timer are the key parameters in this scheme and are described in detail as follows:

### A. Short-DRX-cycle ($T_{SDC}$)

In the proposed scheme, the UE enters a Short-DRX-cycle each time after downloading one complete packet. Thus, the length of a Short-DRX-cycle should be equal to the inter-packet arrival time at the eNodeB buffer. Let $Q_i$ be the data rate in packets/second of the current video segment that user $i$ is streaming, then $T_{SDC_i}$ in number of subframes (i.e. milliseconds) can be determined as:

$$T_{SDC_i} = \left\lfloor \frac{1000}{Q_i} \right\rfloor \tag{4}$$

Hence, a packet is served every $T_{SDC_i}$ and the $UE_i$'s received data rate is limited to $1000/T_{SDC_i}$ packets per second. If the incoming traffic exceeds that rate, it will be delayed in the eNodeB buffer.

### B. On-duration ($T_{on}$)

A packet has to be served entirely during the On-duration $T_{on}$ of a short-DRX-cycle. Thus, the length of the $T_{on_i}$ of $UE_i$ in this scheme is equal to the expected latency to serve the packet. Mathematically,

$$T_{on_i} = \left\lceil \frac{n_i^{RB}}{\gamma_i^{RB}} \right\rceil \tag{5}$$

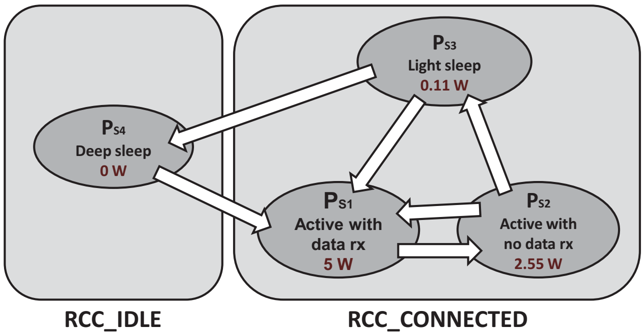



Fig. 4. UE power consumption model [23]

which is the number of subframes required to serve one packet to $UE_i$. $n_i^{RB}$ is the number of physical resource blocks (RBs), that can be assigned both in the frequency and in the time domain, needed to serve a packet and can be calculated as:

$$n_i^{RB} = \frac{packetsize}{(data\, per\, RB)_i} \tag{6}$$

where $(data\, per\, RB)_i$ is the amount of data that can be transmitted to $UE_i$ in one resource block depending on its channel condition, based on the link layer model from [22]. $\gamma_i^{RB}$ is the average number of available RBs that can be allocated to the $UE_i$ in one subframe. It is calculated by estimating the average number of active users competing for resources in one subframe.

We can see that by reserving $T_{on_i}$ subframes as UE On-duration during a $T_{SDC_i}$, overall $UE_i$ will spend the necessary amount of time in the wake-up state so that he can fetch the current video segment in time for playback without any stalls or interruptions.

### C. Other DRX parameters

The DRX-Inactivity-timer ($T_{in}$) parameter is fixed to 1ms, which makes the UE enter into a short-DRX-cycle immediately after receiving a complete packet. Long-DRX-cycles are configured with exactly the same duration as short-DRX-cycles, in other words, the UE follows only one kind of DRX cycle during an active streaming session, in order to avoid unexpected long packet delays.

## V. UE Power Model

The UE power consumption of its radio interface circuitry is modeled as in the 3GPP contribution [23] in which 4 different states of UE activity are considered. The corresponding power consumption is illustrated in Figure 4. In RCC_IDLE mode, the UE stays disconnected from the network and hence stays in deep sleep state. Whereas, in RCC_CONNECTED mode, three states of UE activities are selected: Light sleep, active with data RX and active with no data RX. In the "active with data RX" state, the UE is scheduled for receiving data while in the "active with no RX" state, the UE just receives and decodes control signals.

The Average Power (AP) consumption for user $i$ during an optimization cycle where the DRX parameters are fixed can be calculated using the UE power model and the values of the DRX parameters as follows:

$$AP_i(W) = \frac{P_{s1} \cdot T_{on_i} + P_{s2} \cdot T_{in} + P_{s3} \cdot (T_{SDC_i} - T_{on_i})}{T_{SDC_i} + T_{in}} \tag{7}$$

where $P_{S1}$, $P_{S2}$ and $P_{S3}$ are the powers in the three different RRC_CONNECTED states as shown in Figure 4. The percentage of Power Reduction (PR) due to DRX compared to the case with no DRX is given by the following expression:

$$PR_i = \frac{AP_i\ without\ DRX - AP_i\ with\ DRX}{AP_i\ without\ DRX} \tag{8}$$

As the adaptive DRX parameters in (7) depend on the current video rate, and thus on the current resource share $\alpha_i$, the average power $AP_i$ for user $i$ also depends on the resource share. Therefore, the power reduction (8) for user $i$ also depends on $\alpha_i$.

## VI. Energy Efficient and QoE-driven Resource Optimization

The resource allocation considered in (2) only takes into account the QoE of each user. We extend this QoE-based optimization to make it more energy efficient. Indeed, for a given video, a high quality representation enhances the user's QoE while at the same time, it consumes more energy because of its high data rate, as the UE has to spend more time in the "active with data RX" state. On the other hand, a low quality representation might not meet the user's expectation but can consume less energy due to the low data rate. Therefore, both the user experience in terms of video quality and the UE average power are taken into account in the new optimization problem in order to determine the resource allocation in a LTE cell in a more energy-efficient way.

We consider an LTE cell with a number $N$ of UEs streaming different video contents using DASH, and $\alpha_i$ is the resource share of $UE_i$. $PR(\alpha_i)$ is the percentage of power reduction as defined in (8). Our goal is to determine the resource distribution $\alpha_i$ for $i = 1, \ldots, N$ that jointly maximizes the QoE and power reduction. The optimization problem can be formulated as:

$$\underset{(\alpha_1,\ldots,\alpha_N)}{\arg\max} \quad \sum_{i=1}^{N} U_i(\alpha_i) + K \cdot PR_i(\alpha_i) \tag{9}$$

$$subject\ to \quad \sum_{i=1}^{N} \alpha_i \leq 1 \tag{10}$$

where $K$ is the weight given to the power reduction term. With higher values of $K$, more importance is given to the power reduction and the resources will be allocated such that each UE will save more energy at the cost of MOS. If $K = 0$, (9) is the same as (2), where the power reduction is not taken into account. The optimization problem can be solved in real time, e.g. with a greedy algorithm [24].

## VII. Simulation Results

In our simulation scenario, we have 8 clients in a LTE cell, streaming different video contents using DASH. Each video sequence is encoded into 11 different representations by varying the quantization parameter of an H.264/AVC codec.

The optimizer determines the resource share, transmission rates and DRX parameters for each client with a period of 1 second. The LTE profile and simulation parameters are listed in Table I.

TABLE I. SIMULATION PARAMETERS

| | |
|---|---|
| **LTE profile** | |
| Carrier frequency | 2 GHz |
| System bandwidth | 5 MHz |
| Link layer model | [22] |
| Channel model | Urban macrocell |
| Shadowing standard deviation | 8 dB |
| Correlation distance of Shadowing | 50 m |
| **Simulation parameters** | |
| Number of users | 8 |
| Simulation runs | 50 |
| Simulation time | 300 sec |

The results are evaluated in terms of MOS and power reduction during a DASH session. The following different cases are compared:

- **NonOpt-withoutDRX:** Standard DASH streaming without any resource optimization where a round robin scheduler distributes the resources equally among the users. DRX mode is disabled.
- **Opt-withoutDRX:** DASH streaming where the QoE-driven optimizer determines the resource share of each user at the eNodeB according to (2). DRX mode is disabled.
- **Opt-withDRX:** DASH streaming where our energy efficient and QoE-driven optimization determines the resource share of each user at eNodeB according to (9). DRX mode is enabled with our proposed adaptive DRX scheme.

Fig. 5 shows the comparison of non-optimized DASH streaming over LTE (NonOpt-withoutDRX) with our proposed approach (Opt-withDRX) with $K = 0$ in terms of mean MOS and mean power consumption. While the QoE optimization brings an improvement in overall MOS of 0.35, the proposed adaptive DRX parameters allow us to decrease the average power consumption by 27%.

We then evaluate the effect of joint optimization (9). Fig. 6 describes the trade-off between the overall MOS and power saving. By enabling DRX together with QoE optimization (Opt-withDRX, $K = 0$), on average, the average power is reduced by 32% without any perceptible loss in MOS. The Opt-withDRX curve in Fig. 6(b) shows that, by increasing the weight $K$ of the power reduction factor in the optimization problem (9), the energy consumption can further be reduced. However, this also leads to a decrease in overall MOS as shown in Fig. 6(a). It can be seen that, for smaller values of $K$, there is a meaningful reduction in power consumption without any significant degradation in mean MOS. For example, at K=3, there is about 18% further decrease in power consumption with only 4% loss in MOS.

Furthermore, the mean MOS and mean power consumption of individual video sequences are evaluated in Fig. 7 to explain power saving chances for each video sequence using DRX and the effect on its video quality. In Fig. 7(b), for low data rate

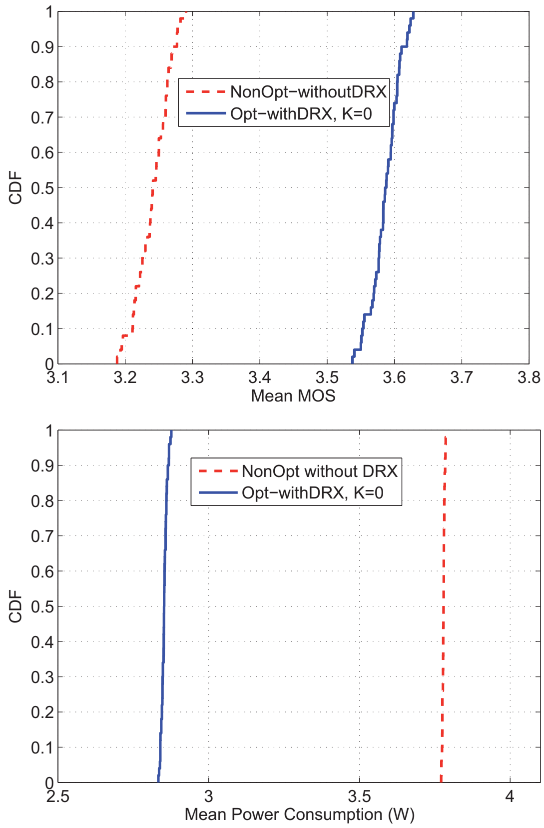
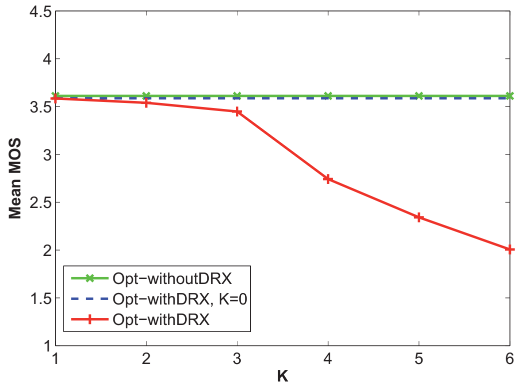



Fig. 5. Comparison in terms of mean MOS and mean power consumption over 8 users

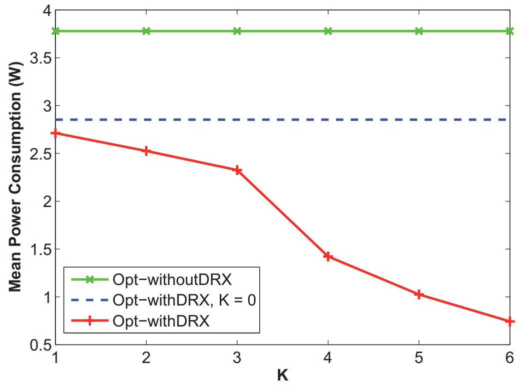
video sequences like *akyio* and *container*, a lot of power is saved by enabling DRX mode with the proposed adaptive DRX scheme because of relatively large pauses between transmissions and more power saving chances. On the other hand, for the high data rate video sequences like *bus*, *coastguard* and *harbour*, there are fewer power saving opportunities between the transmissions and hence relatively less power is saved. On the other hand, if we look at the effect on the mean MOS of individual video sequences in Fig. 7(a), there is no serious degradation in terms of MOS for any video type.

## VIII. CONCLUSION

In this work, we determine adaptive DRX parameters for multiple adaptive HTTP streaming sessions in a QoE-optimized LTE system in order to reduce the average power of the UEs' radio interface without lowering the visual quality of the video and thus make the QoE-driven system more energy-efficient. In a further step, we extend the existing QoE-optimization problem by jointly considering the potential average power reduction that can be achieved by reducing slightly the transmission rate and thus enable to save more energy with longer DRX sleep periods. Simulation results show that the mean MOS over all users can be improved and at the same time, an average reduction of the power of 32% can be achieved with the proposed adaptive DRX parameters. Moreover, we show how the joint optimization problem can trade off between visual quality and additional energy saving gains.

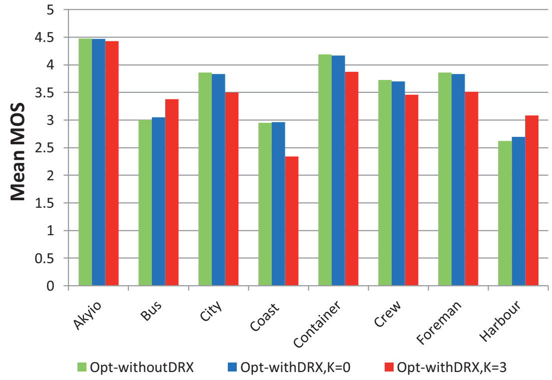



(a) Mean MOS of all users in function of $K$

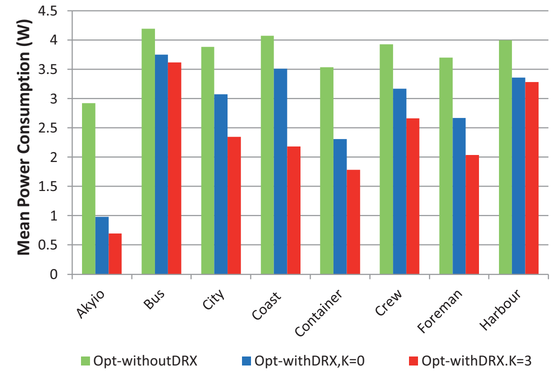



(b) Mean power consumption of all users in function of $K$

Fig. 6. Trade off between mean MOS and mean power consumption




(a) Mean MOS of individual users




(b) Mean power consumption of individual users

Fig. 7. Individual performance averaged over 50 simulations. Each user is streaming a different video.

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