Streaming over 3G and LTE: How to Save Smartphone Energy in Radio Access Network-Friendly Way

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ABSTRACT

Energy consumption of mobile devices is a great concern and streaming applications are among the most power hungry ones. We evaluate the energy saving potential of shaping streaming traffic into bursts before transmitting it over 3G and LTE networks to smartphones. The idea is that in between the bursts, the phone has sufficient time to switch from the high-power active state to low-power states. We investigate the impact of the network parameters, namely inactivity timers and discontinuous reception, on the achievable energy savings and on the radio access network signaling load. The results confirm that traffic shaping is an effective way to save energy, even up to 60% of energy saved when streaming music over LTE. However, we note large differences in the signaling load. LTE with discontinuous reception and long inactivity timer value achieves the energy savings with no extra signaling load, whereas non-standard Fast Dormancy in 3G can multiply the signaling traffic by a factor of ten.

Categories and Subject Descriptors

C.4 [**Performance of Systems**]: [Design studies]; D.2.8 [**Software Engineering**]: Metrics—*performance measures*

Keywords

energy, streaming, 3G, LTE, smartphone

1. INTRODUCTION

Energy consumption of smartphones is a growing concern. The rate at which their capabilities improve and data intensive usage grows far exceeds the rate at which battery technologies evolve. Streaming applications are extremely popular nowadays but they are among the most power hungry ones. Video streaming uses a lot of energy to receive the content and to decode and display the video. The problem of communication energy expenditure is severe because many streaming services send content as constant bit rate (CBR) traffic resulting to the radio interface being constantly on and quickly depleting the battery. Shaping streaming traffic into bursts have been proposed as a solution to reduce the power when streaming over Wi-Fi. The idea is to use the available bandwidth more efficiently in order to reduce the amount of time the radio is kept on.

In this paper, we evaluate the potential of such traffic shaping mechanism to save energy of smartphones to which audio and video is streamed over 3G (HSPA) and LTE networks. We used a fully isolated and complete HSPA and LTE test networks, which made it possible at the same time to study the behavior of commercial smartphones and to quantify the impact of different network configurations on both the end device and the network. We quantify the impact of different radio access network (RAN) configurations on the achievable energy savings by considering different inactivity timer values and discontinuous reception mechanisms. In addition to the smartphone energy savings, we studied also the impact of shaping streaming traffic into burst on the RAN signaling load because globally many major operators have suffered service quality deterioration and even network outages because of signaling storms created by smartphone applications [1].

Our results show that traffic shaping is effective in saving energy for streaming applications and we measure up to 20% savings in video streaming over 3G and up to 60% savings in audio streaming over LTE. However, some video streaming services, such as YouTube, may significantly hurt the savings through application level signaling traffic that keeps the radio awake. Interestingly, the most attractive strategies from both client's and network operator's perspectives seem to be different for 3G and LTE. In 3G, the best choice seems to be to use shorter inactivity timers with traffic shaping. In LTE, it appears to be to use traffic shaping and discontinuous reception mechanism together with long inactivity timers. The most harmful case for the RAN is when the smartphone uses a mechanism called non-standard Fast Dormancy to tear down the RAN connection whenever the device is idle for long enough time, which can multiply the signaling traffic even by a factor of ten.

2. BACKGROUND

2.1 Energy Consumption

The three activities that typically consume most of the energy of a smartphone while using streaming services are radio communication, computation (decoding audio and video), and display and multimedia presentation. In this work, we

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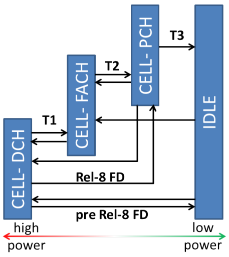


Figure 1: 3G RRC state transitions including standard and non-standard Fast Dormancy(FD).

only focus on reducing the communication energy consumption. The amount of that energy consumed depends on the joint effect of cellular network interface being used and the traffic patterns generated by the streaming service.

Figure 1 sketches the state machine of 3G radio resource protocol (RRC) [2]. There are four main states CELL_DCH, CELL_FACH, CELL_PCH, and IDLE. Transitions happen either when the regular timers (T1, T2, and T3) expire or when Fast Dormancy (FD) is activated (Rel-8 FD or pre Rel-8 FD). These different states correspond to different amounts of radio network resources allocated to the mobile device. These timer values are in the order of several seconds (typically T1 is close to 10s) and they are purely network controlled. The key insight is that the device draws roughly the same amount of energy in a given state regardless of how much data is transmitted. Hence, staying in a high-power state after transfer is finished is extremely harmful from energy consumption perspective. This wasted energy is often referred to as *tail energy* [6].

Fast Dormancy (FD) reduces the amount of tail energy. It comes in two flavors. Pre-Release-8 (or legacy) FD is a non-standard mechanism which is still used by some devices. The idea is to tear down RRC connection altogether after the connection is idle for a certain duration. The problem is that it dramatically increases the signaling load of the network, as reported in [4], because the terminal needs every time to re-establish the RRC connection for the next data transmission. In Release-8 Fast Dormancy the mobile device can request the network to transition directly to CELL_PCH state from CELL_DCH (see Figure 1). This version is more network friendly since switching back to CELL_DCH state from CELL_PCH requires much less signaling than from IDLE state and usually the difference in power draw between CELL_PCH and IDLE states is not significant. Furthermore, there is a significant difference in the delay between the IDLE → CELL_DCH and CELL_PCH → CELL_DCH transitions, which is often directly visible to the user. CELL_PCH state is sometimes not used by operators, if the network does not support that feature.

LTE (Long Term Evolution) forms the next generation of cellular network technology and LTE networks have already been deployed in many countries. LTE state diagram only contains two states: RRC_IDLE and RRC_CONNECTED [3]. Similar to 3G, there is an inactivity timer associated to the transition from the connected to the idle state. Thus, similar tail energy phenomenon exists also for LTE.

LTE includes a so called discontinuous reception mechanism specifically to be used in the RRC_CONNECTED state, hence called connected mode DRX (cDRX), which can drastically reduce the tail energy. Figure 2 illustrates this mechanism. The idea is that after no packets have been received for a time period specified by cDRX inactivity timer (DRX_{idle}), the device starts a duty cycle so that it wakes up only periodically (every DRX_c) for DRX on-duration specified amount of time (DRX_{on}) to check for new incoming packets. If no packets are received during an interval specified by the inactivity timer (T_{idle}), the device transitions from RRC_CONNECTED to RRC_IDLE state. Also discontinuous transfer (DTX) exists which is the counterpart of DRX for the upstream packet transmissions. Since we focus on streaming to the smartphone, DRX is the more relevant mechanism for our experiments.

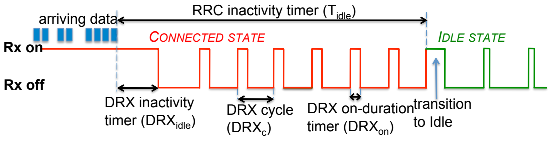
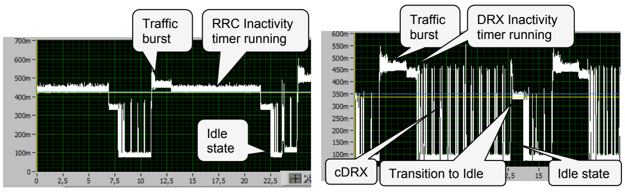

arriving data
RRC inactivity timer (T_{idle})
CONNECTED STATE
IDLE STATE
Rx on
Rx off
DRX inactivity timer (DRX_{idle})
DRX cycle (DRX_c)
DRX on-duration timer (DRX_{on})
transition to Idle

Figure 2: DRX timers in LTE.



(a) cDRX disabled

(b) cDRX enabled

Figure 3: Tail energy is reduced dramatically with cDRX. X-axis is time (s) and Y-axis current (mA).

We show in Figure 3 an example power trace of packet transmission over LTE with and without cDRX. The tail energy is reduced a lot when cDRX is activated. While it is clear from these figures that cDRX saves energy, the magnitude of the savings depends also on the configuration of the cDRX parameters.

2.2 Streaming with traffic shaping proxy

HTTP over TCP is today the most commonly used protocol suite for mobile video delivery by streaming services. The streaming clients do initial buffering of the content which is visible to user as start-up delay. We refer to this phase as Fast Start. Usually, the initially buffered data is sent by the server at a faster rate than the rest of the stream. After Fast Start, different approaches are used to deliver the rest of the content to the streaming clients over TCP. For more details on the different techniques, we refer the reader to [10].

The most energy efficient way to deliver the entire stream content is to download all of it at once after which the network interface transitions to a lower-power state. However, if the user does not watch the whole video or listen to the entire song, downloading all-at-once downloads unnecessary data and wastes energy. To achieve the most attractive tradeoff between the level of pre-fetching and energy efficiency, content should be received in bursts. We used a proxy server to reshape the streaming traffic into bursts in order to generate ON-OFF patterns. The proxy server receives multimedia requests from the smartphones and then forwards the request to the server. In response, proxy receives data from the server and accumulates it for a period of time, and then sends the data as a single burst. We denote the time interval between two consecutive bursts as the burst interval (T). This traffic shaping would allow the network interface to transition into low power consuming states in between two consecutive bursts if T is long enough, such as in Figure 3.

In our earlier work [9], we identified that the maximum value of the burst interval is bounded by the amount of data transferred during Fast Start and the client TCP receive buffer size. If the size of proxy generated burst is larger than the client TCP receive buffer size, the energy consumption is higher than in the case where it exactly matches the buffer size. Consequently, the traffic shaper in the proxy checks for any zero window advertisements in the TCP acknowledgements (ack) sent by the client in order to identify whether the current burst size is too large. In this way, by probing different burst sizes, the proxy is able to reach the optimal burst interval for which the energy consumption at the client is minimized.

3. METHODOLOGY

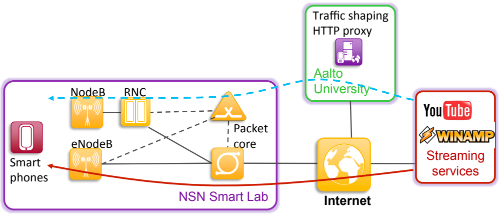


Figure 4: We streamed directly from the server (solid red arrow) and via the traffic shaping proxy (dotted blue arrow) using 3G and LTE test networks.

Figure 4 illustrates the setup we used for the measurements. We streamed both audio and video to mobile devices connected to the test networks but present only a few audio streaming results because of space constraints. LTE was only used for audio streaming. We streamed audio from Finnish radio stations and video from YouTube. A video called "Big Buck Bunny" (duration: 9min 57s) was used in experiments with N900 and Lumia 800 and video called "Amar Akbar Anthony - Parda Hai Parda - Mohammad Rafi" (duration: 8min 18s) with Nexus One. Audio streaming sessions lasted ten minutes each time. Both experiments were done in two ways: direct streaming from the server and streaming through our traffic shaping proxy. The proxy always selected the estimated optimal burst interval for each test case. We measured the current draw of the smartphone and collected traffic traces and signaling logs during each streaming session. Current was measured using external meters connected to the smartphone's power input. We used in total four different smartphones in the measurements: Nokia N900 (Maemo), Nexus One (Android 2.3.6), Lumia 800 (WP 7.5), and HTC Velocity (Android 2.3.7) as the only LTE capable phone.

We performed the measurements in a completely isolated RF room where we had access to a complete HSPA and LTE test networks of Nokia Siemens Networks. The LTE network operates on the 2600 frequency band and the 3G (WCDMA) network operates on the 2100 MHz frequency band. The downlink capacity of the 3G subscription was 6 Mbps, while the LTE peak rates were 100 Mbps for download and 50 Mbps for upload. We captured 3G traffic from the Gn interface i.e. between SGSN and GGSN and LTE traffic from S1 interface.

RAN	Test cases	Network configuration
3G(HSPA)	default(def)	T1=8s, T2=3s, T3=29mins
	no PCH(noPCH)	T1=8s, T2=10s, CELL_PCH off
	aggressive(aggr)	T1=6s, T2=2s, T3=29mins, CELL_PCH on
LTE	default without DRX	T_{idle}=10s, DRX off
	default with DRX	T_{idle}=10s, DRX_{idle}=750ms, DRX_c=640ms, DRX_{on}=20 ms
	default with DRX, long idle	T_{idle}=20s, DRX_{idle}=750ms, DRX_c=640ms, DRX_{on}=20ms

Table 1: Test cases with different network parameter configurations.

Table 1 summarizes the network configurations for the different test cases. For HSPA measurements, we used three different network configurations. We varied the values of inactivity timers T1 and T2, and enabled or disabled the CELL_PCH state. Default configuration refers to configuration according to the vendor recommended parameters. We have measured similar values being used in commercial networks in Finland. Aggressive configuration refers to shorter values of T1 and T2. T2 value was set to a longer value when the CELL_PCH state was disabled because that is recommended to reduce the number of transitions to IDLE state and keep signaling load reasonable. LTE experiments were done with cDRX disabled and enabled and with shorter and longer inactivity timer value. To keep the number of test cases reasonable, we did not explore the cDRX parameter space but used always the same profile when enabled.

The measurements were conducted in a laboratory environment without any sources of interference and with only the test device connected to the cell. Moreover, a single streaming session was long enough to capture many burst periods. These two reasons give us confidence that the results are representative and comparable between the test cases.

4. YOUTUBE STREAMING OVER HSPA

4.1 Energy Consumption over HSPA

We first look at power consumption of YouTube streaming over the 3G test network. Figure 5 summarizes the results. The average current is computed over the whole duration of the video playback.

We learn several things from the results. First, the traffic shaping proxy helps save energy in all cases except for Lumia 800. The reason is that Lumia 800 YouTube client receives the test video in "all-at-once" manner. In other words, the whole video is downloaded fast in the beginning of the streaming session. The download completes in about two minutes. This is not the case for the other devices' players for which the server throttles the download rate and the download completes roughly two minutes before the end of playback. Because Lumia 800 receives all the video right

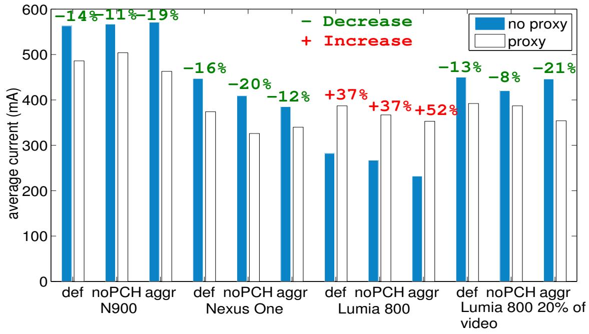


Figure 5: Power savings achieved with traffic shaping while streaming YouTube videos over 3G.

away, the radio can transition to low power state for the rest of the playback duration which it cannot do if the proxy is present. Thus, using the proxy leads to a higher energy consumption.

Concerning the network configuration, we first note that shorter timers do not generally help to save energy without traffic shaping. If traffic is shaped into bursts, slightly more energy can be saved with more aggressive timer values in the case of N900 and Lumia 800. The reason is quicker transition to lower power state after receiving a burst. However, this observation does not hold in the case of Nexus One. The reason is the legacy FD used by it. We checked manually from the traffic and power traces that when receiving a large burst of traffic it uses a timer of about 5 s after which it tears down the RRC connection. For some reason, when receiving small amounts of traffic (few packets), the timer seems to be slightly longer, approximately 6.5 s. This first timeout is shorter than T1 value in all the tested scenarios but 6.5s is just a bit longer than the T1 value in the aggressive setup. As a consequence, Nexus One activates the legacy FD in most of the cases and the energy savings are similar between the default and aggressive configurations.

Finamore et al. discovered that 60% of YouTube videos are watched for less than 20% of their duration [8]. For this reason, the all-at-once strategy used by Lumia is not always energy efficient. We plot in Figure 5 the average current also in the case for Lumia where watching is interrupted after 20% of the total duration. We notice that the proxy saves energy in this case, which is obvious since the all-at-once strategy downloads a lot of unnecessary content.

Finally, the energy consumption overall differs quite a lot between the devices, which is mostly explained by the different hardware components used in the phones.

4.2 Impact of YouTube Background Traffic

Overall, the energy savings are not as large as we initially expected. The reason turned out to be an artifact of YouTube control traffic which mixes with the content bursts. Figure 6 illustrates what happens during YouTube streaming via the proxy for Nexus One as an example. The client establishes several TCP connections to YouTube servers. The proxy shapes only the traffic of the connection that carries the video content. Those packets are visible as tall bursts (black) in the traffic trace on top and the packets of other connections are visible as shorter spikes (red). The other packets are only few (note the log scale) and far in between but they interleave the video content bursts in an unfortunate manner. The impact is visible in the current trace below. The radio interface transitions to high power state to receive those few packets in between the large bursts and overall energy consumption is increased.

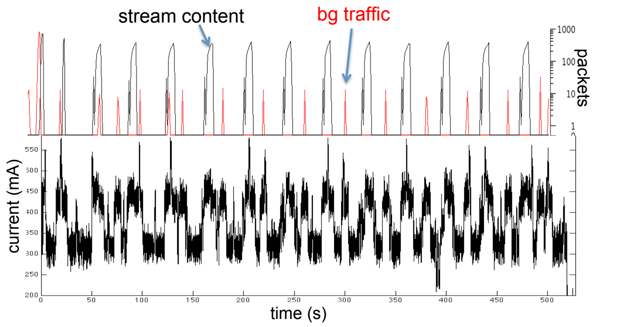


Figure 6: Traffic and power traces of Nexus One while streaming from YouTube via the proxy over 3G. Video content bursts (in black) are interleaved with other background traffic (in red).

The background traffic persisted in every measurement round with N900 and Nexus One but did not exist with the Lumia phone. Lumia uses a native app while the two others use browser-based Flash/HTML5 player. We looked at this traffic more closely and it turned out to consist of a varying number of connections, depending on the device, and it contains three types of activity: 1) fetching the actual web page, images of related videos, and the player (i.e. Flash or HTML5) in the beginning of the streaming session, 2) reporting to YouTube statistics server using HTTP GET requests periodically through the entire playback, and 3) fetching the content to display after the playback is over just before the end of the session. Out of these, only the periodic reporting of statistics has a major impact on overall energy consumption.

We analyzed how severe the impact of this background traffic is. To this end, we first manually isolated the best (almost no bg traffic in between bursts) and worst case bursts (bg traffic in between bursts) from the current traces for each studied case. Then, we computed the average current draw for both cases and compared them. Note that since streaming through the proxy generates periodically regular bursts, we can get an estimate of the overall average current draw by just focusing on a single burst. The results indicate that the background traffic can increase the average current from 2% up to 27%.

4.3 RAN Signaling Traffic & Packet Loss

The energy savings achieved by shaping traffic into bursts come with a price to pay. The savings are achieved by increasing the number of RRC state changes during the streaming session. Each state change costs some extra signaling traffic. We extracted the number of state changes for each test case from the signaling logs and since we know the number of signaling messages required for a specific state change, we were able to compute the total number of signaling messages. The results are shown in Table 2.

There is a striking difference between Nexus One and the two other phones. The reason lies in the legacy FD that

Device	Network conf	#msgs / min		Change
		No proxy	Proxy	
N900	default	7	26	3.7x
	no PCH	6	47	7.8x
	aggressive	6	37	6.2x
Nexus One	default	11	100	9.1x
	no PCH	11	96	8.7x
	aggressive	14	109	7.8x
Lumia 800	default	8	36	4.5x
	no PCH	10	62	6.2x
	aggressive	8	35	4.4x

Table 2: Increase in signaling traffic due to traffic shaping when streaming YouTube videos.

Nexus One uses. Since that mechanism tears down the RRC connection in between each video content burst, the connection must be re-established every time a new burst starts, which requires a lot more signaling than transition from CELL_PCH to CELL_DCH state.

For the same reason, reshaping the traffic into bursts while not having the CELL_PCH state enabled increases the signaling load more than in the case where that state is enabled. The reason why signaling load is even higher in the case of Nexus One compared to the case where CELL_PCH state was disabled for N900 and Lumia is the YouTube background traffic, In the case of Nexus One, those periodic packets emerge right in the middle of the video bursts which causes extra state transitions each time.

The shorter timer case for N900 shows a surprisingly high increase in signaling load when the proxy is applied. The reason turned out to be that N900 applied legacy FD after some bursts. The logic explaining how N900 decides when to apply that mechanism remains unclear to us.

We also investigated whether introducing the proxy increases the amount of retransmitted bytes. The rationale is that when a burst arrives to the radio access network, the device needs to transition to CELL_DCH state which causes non-negligible delay (in the order of a few seconds in the worst case) during which TCP retransmission timeout may expire for the first packets which will then be retransmitted. Indeed the case. For N900 and Nexus One, which download the video content slower than Lumia, the ratio of retransmitted bytes systematically increased from almost zero to somewhere between 1-2%. Lumia's fast download already caused a larger amount of bytes to be retransmitted and, therefore, the increase was not as substantial.

5. STREAMING AUDIO OVER LTE

We only measured audio streaming over LTE but the results give indications of what the results would be for video streaming cases as well. The results in Figure 7 show that traffic shaping can save some energy even when cDRX is disabled. However, when shaping the traffic through the proxy, we can save almost up to 60% of energy in the best case when cDRX is enabled. Moreover, we note that enabling cDRX does not help at all when streaming directly from the server.

The figure shows also that when DRX is enabled, even larger savings can be obtained by increasing the inactivity timer value from 10s to 20s. The reason is the following. When the inactivity timer value is 10s, the LTE protocol transitions from Connected to Idle state in between receiving the bursts because the timer is shorter than the burst interval. This transition causes non-negligible amount of energy to be spent. When the timer is increased to 20s, this transition no longer occurs and the average current is decreased. Even further savings should be possible when increasing the burst interval and optimizing the cDRX profile. We expect similar results to apply for the video streaming case except that the relative energy savings will be smaller because the baseline current is higher due to active display and more computational work.

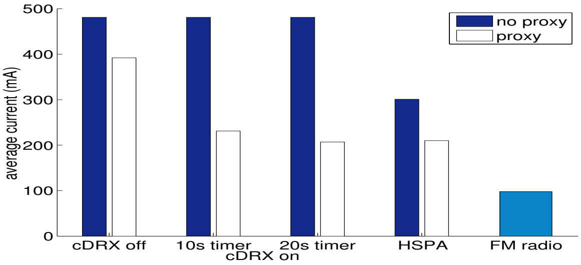


Figure 7: Power savings achieved with traffic shaping while streaming music over LTE.

As for the signaling load, there can be two kind of state transitions as there are only two states in LTE RRC. Each transition causes a certain amount of signaling within the network. We note that using the configuration that delivers largest energy savings, namely cDRX enabled and inactivity timer longer than the burst interval, there is no increase in signaling traffic due to state transitions. The cDRX mechanism itself does not cause any extra signaling load to the RAN compared to a case where a phone is in connected mode without DRX.

In order to compare different technologies, we measured also the case when streaming over 3G with the same phone (HSPA in Figure 7). There is a notable difference in the average current when streaming directly from the server in favor of HSPA but the difference becomes negligible if cDRX is activated. The figure includes also the current draw caused by listening FM radio with the same smartphone. Although the energy savings can be cut by more than half with traffic shaping and cDRX, the resulting current is still double the plain old radio. We measured similarly the FM radio current of N900 and the result was the same 100 mA than with the LTE phone. However, the lowest average currents we measured for audio streaming over 3G are only marginally higher than the average FM radio current.

6. RELATED WORK

Energy consumption of Wi-Fi in mobile devices has been widely studied in the past. Representative examples are presented in [12,14] which both studied the energy consumption of video streaming over Wi-Fi access. The focus of this paper is solely on cellular networks. Several papers focus specifically on LTE's energy consumption. Bontu et al. describe the potential of DRX to reduce the mobile device's power consumption and discuss the importance of configuring the parameters in [7]. The simulations on streaming workload suggest that up to 50% of power savings are achievable. We did not observe any benefits from using DRX with CBR streaming traffic. However, the DRX parameterization may have a large impact on that case. Huang et al. looked at

LTE energy efficiency in general in [11] using a model they derived using an LTE phone operated in a commercial network. Surprisingly, the authors arrive to a conclusion that LTE is very energy inefficient even with DRX enabled. Comparing the power draw they report (over 1W) to the current we measured (less than 100mA or 370mW in Figure 3) when cDRX is active and the device is in between On cycles shows a big difference, which raises a question whether cDRX was fully supported by the network equipment and the device in their experiments.

Many papers have also studied the energy efficiency of 3G communication. Xiao et al. were one of the first to study the energy consumption of YouTube streaming over both Wi-Fi and 3G [15]. We go beyond the scope of that work by considering the impact of traffic shaping and different network configurations, including LTE. Balasubramanian et al. performed a measurement study on the energy consumption of 3G communication [6] but did not consider streaming applications in their study. Qian et al. proposed a traffic shaping scheme for YouTube and compute estimates on potential energy savings with that scheme [13]. Our earlier work included also some measurements results from 3G network [9]. A more recent and thorough measurement study on different mobile video streaming services and the resulting energy consumption on different mobile OSs and devices is presented in [10].

7. CONCLUSIONS

We investigated how to save smartphone energy while using streaming services over 3G or LTE network. We paid special emphasis on the different network parameter configurations that may have an impact on the phone's energy consumption, and on the impact of the parameters and traffic shaping on the RAN signaling load. Traffic shaping is effective in saving energy for streaming applications. Our results indicate that the most attractive strategy that provides a good balance between energy savings for the phone and signaling load for the RAN is different for 3G and LTE. We obtained the best results for 3G by shaping traffic and using shorter than default inactivity timers. The best strategy for LTE seems to be to use traffic shaping together with cDRX and long inactivity timer value. In contrast, clearly the worst strategy is the use of legacy FD in 3G. It is worth noting that also 3G specification includes a discontinuous reception mechanism, namely Continuous Packet Connectivity (CPC) [5]. It provides essentially a similar mechanism for 3G's CELL_DCH state as the cDRX does for LTE's connected state. Once that mechanism gets fully supported by phones and RAN equipment, it may change the best practice of 3G to be aligned with LTE.

Acknowledgment

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