How Video Streaming Consumes Power in 4G LTE Networks

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***Abstract*—With the increasing adoption of mobile 4G LTE networks, video streaming as the major contributor of 4G LTE data traffic, has become extremely hot. However, the battery life has become the bottleneck when mobile users are using online video services. In this paper, we deploy a real mobile system for power measurement and profiling of online video streaming in 4G LTE networks. Based on some designed experiments with different configurations, we measure the power consumption for online video streaming, offline video playing, and mobile background. A RRC state study is taken to understand how RRC states impact power consumption. Then, we profile the power consumption of video streaming and show the results with different impact factors. According to our experimental statistics, the power saving room for online video streaming in 4G LTE networks can be up to 69%.**

I. Introduction

Currently, video streaming demand is the significant contributor of cellular network data traffic. Through 2014, video services accounted for almost 45% of total mobile data traffic [6], while the occupancy percentage also is still increasing. However battery dying is still an unsolved issue on current mobile devices, so power consumption in video streaming on 4G LTE phones becomes an attractive issue.

Video streaming stands for the concept of playing real-time video by retrieving source segments from web video server simultaneously, and it is the most popular online video playing technique. In this paper, we concern about 1) the power consumption distribution for online video streaming, especially the portion consumed by network activities; 2) the impact factors which influence the power consumption of mobile devices; and 3) the potential room for energy saving in 4G LTE networks. This paper presents a comprehensive plan for power measurement and modeling of video streaming in 4G LTE Networks. From the designed experiments, we attempt to figure out the key impact factors and the total potential power saving room.

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II. Experimental Methodology

A. Power Experiments

Our power measurement and modeling are mainly conducted on Samsung Galaxy S5 in T-Mobile LTE networks. To measure the power consumption of the tested mobile phone, we deploy Monsoon [2] power monitor to track the real-time power consumption of target devices. To learn the power consumption for each part of online video streaming [7], we go through a detailed power breakdown.

B. RRC Experiments

The RRC protocol [5] belongs to the Universal Mobile Telecommunication System, and the RRC states will impact power performance at UE-side [8]. In order to get the precise length of each RRC state, we run experiments with iPerf [1] tool, which can establish UDP/TCP connections between clients and set up customized packet deliveries. In this case, we can retrieve the total length of RRC tail which impacts the power consumption of online video streaming in 4G LTE netowrks. The QXDM tool [3], which can record eight RRC states (*Closing, IRAT To LTE Started, Suspend, Connected, Connecting, Idle Camped, Idle Not Camped, Inactive*), is used to collect instant RRC states.

C. Traffic Measurement

To compare the RRC states and network traffic, it is necessary to record the packet transmissions of mobile phones. We utilize the mobile application Wireshark [4] analyzer to retrieve the traffic transmission records during video streaming experiments.

III. Power Profiling for Video Streaming

Figure 1 can bring us the preliminary intuition of power consumption of online video streaming. The online power is the instant mobile power when video streaming service is using in 4G LTE networks. We can divide the streaming power curve into different stages: promotion, fully connected transmission, RRC tail. All these three stages exist in each video file downloading cycle.

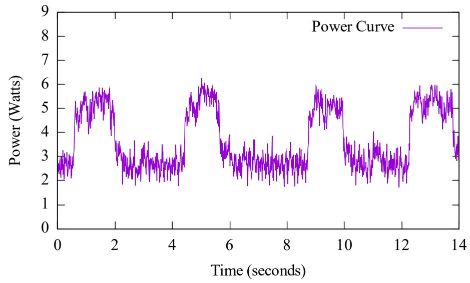

Fig. 1. Video Streaming Power Consumption

A. Detailed RRC Estimation

It is well-studied that RRC state is a factor that impacts the power consumption [9], and we monitor and record all the RRC states during the video streaming processes.

According to preliminary results, our traces can show six RRC states except *IRAT To LTE Started* state and *Inactive* state during the packet transmission tests. An entire RRC state changing procedure should experience this process: *Idle camped* - *Connecting* - *Connected* - *Closing* - *Idle Not Camped* - *Idle Camped*. In RRC *connected* state, mobile phone will consume higher power, while in *Idle* state it will consume lower power.

From Figure 2, we can see that when a traffic period ends, the power consumption will not drop to offline level immediately. The power will retain in a relative high level for about 10.3 seconds, and this period corresponds to the tail period of RRC.

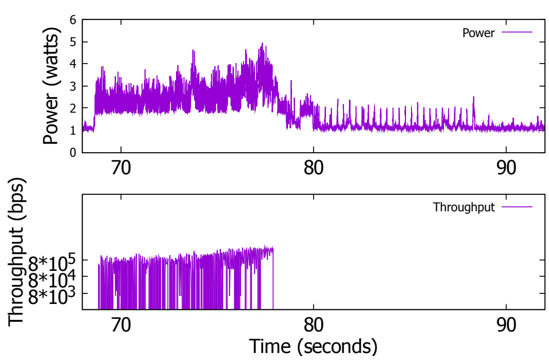

Fig. 2. Tail Power Analysis

B. Power Profiling based on RRC States

During the transmission process, the RRC state changes according to the downloading status. When a video segment starts to be downloaded, the phone enters *Connected* state, which changes the phone into a high power consumption mode. During the RRC *Connected* period, the power rises to $P_{connected}$.

After the end of the last packet delivery, the RRC state is ready to switch to *Idle* state. As in the previous studies, the RRC state will go in a RRC tail period before it goes to *Idle* state. The power of smartphone drops to P_{tail} while the RRC state goes in RRC tails. Based on the our observations, we divide the RRC tail period into two parts, High Consumption Tail (HCT) and Low Consumption Tail (LCT), which last 10.3 seconds in total. The first tail period is High Consumption Tail, which consists the dropping period after the end of each packet delivery, with the instant power P_{HCT}. The length of HCT period, T_{HCT}, is a stable value in single trace, but not consistent among different traces. The period after HCT is LCT, which produces a constant power consumption for a period of time, T_{LCT}. Note that, sometimes in video streaming, the time interval between each segment downloading period is less than 10.3 seconds. So in the real streaming, RRC tail sometimes goes back to RRC *Connected* state directly.

TABLE I
POWER MODELING

	Case01	Case02	Case03	Case04	Case05
$P_{connect}$(w)	5.392	5.489	5.55	4.72	4.64
P_{HCT}(w)	3.455	3.508	3.286	3.701	3.77
P_{LCT}(w)	2.58	2.58	2.58	2.69	2.68
$P_{offline}$(w)	2.34	2.34	2.34	2.47	2.47
$T_{connected}$(s)	1.4	1.28	1.12	2.66	2.6
T_{HCT}(s)	2.56	2.46	2.2	0.94	0.7
$P_{addtional}$(w)	3.052	3.149	3.21	2.25	2.17
P_{HCTadd}(w)	1.115	1.168	0.946	1.231	1.307
P_{LCTadd}(w)	0.24	0.24	0.24	0.22	0.21

As shown in Figure 3, the same pattern exists in all the three traces. This pattern mainly consists of promotion stage, fully connected stage, HCT stage and LCT stage. Table I shows the approximate values for our power modeling of online video streaming. $P_{addtional}$, P_{HCTadd} and P_{LCTadd} represent the additional power introduced by fully connected stage, HCT stage and LCT stage, comparing to offline video playing power.

C. Different Factors

Other factors including the network condition also will affect the power consumption of video streaming.

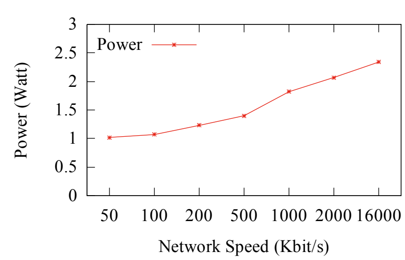

Fig. 4. Network Condition Effect

1) Network Conditions: From the traces of iPerf tests and our experiments, we can capture the power consumption of phone under different network speeds. Figure 4 shows the power consumption grows with the increasing of network speed. However, the results also indicate that the growth in power is not in same rate of growth in the speed. When the

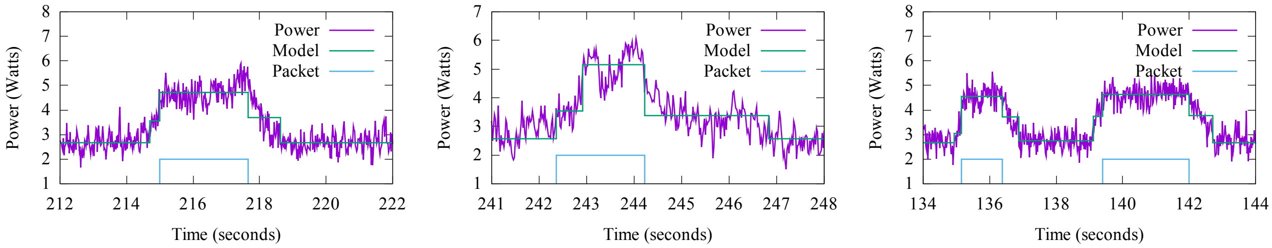

Fig. 3. Power Modeling

speed doubles, the power only increases a little. According to the figure, we can draw the conclusion that the energy consumption for video file transmissions will be decreased with higher network speed.

2) Different Operators: We choose AT&T as the secondary service provider and we apply the experiments with same configurations on an AT&T accessed Samsung S5 smartphone. The results show that the average power consumption of offline video playing on this phone is 2.467 Watts, which is extremely close to our result on T-Mobile S5 phone, 2.47 Watts. As shown in Figure 5, which is one of the examples from our traces, we can clearly see that the power consumption curve is following the same pattern as we discovered on T-Mobile S5 phone. The length of RRC tail is also 10.3 seconds. A notable difference is that, there is no clear distinctions between HCT and LCT periods in AT&T traces.

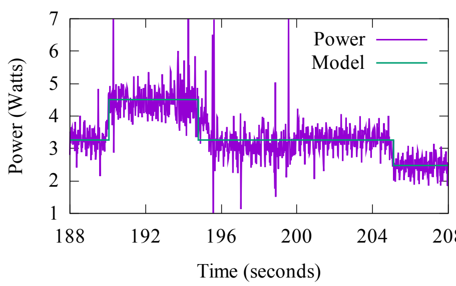

Fig. 5. AT&T Modeling

IV. Potential Energy Saving

We test the downloading mode of video streaming, in which all video segments are downloaded in one time. This downloading mode is the extreme case for online video streaming, and it can help us to find out the maximal power saving in 4G LTE networks on mobile phones. This mode can eliminate all unnecessary RRC tails, promotions, demotions of TCP connection. In this mode, the network part will consume the least energy among all testing traces. The formula used to count the power saving room is ($E_{streaming}$ - $E_{downloading}$) / $E_{streaming}$.

As we calculated, the saving room can be up to 69%, and it is a big power saving for online video streaming. The results of our case studies are listed in Table II.

TABLE II
Saving Room

	Streaming Energy(J)	**Downloading Energy(J)**	**Saving Room(%)**
Case1	409.2	124.3	69.62%
Case2	343.5	124.3	63.82%
Case3	213.8	124.3	41.86%
Case4	235.5	124.3	47.19%
Case5	273.6	124.3	54.56%
Case6	318.9	119.0	62.69%
Case7	306.5	119.0	61.17%
Case8	352.6	119.0	66.25%
Case9	88.95	68.0	23.55%

V. Conclusion

This paper focuses on the measurement and modeling of smartphone power consumptions of video streaming in 4G LTE networks. We present a compound platform to collect the power, throughput and RRC state data on mobile phones. This paper analyzes the relations between RRC states and power consumption in 4G LTE networks, and other factors that influence the power consumption. Our results show improved transmission pattern can improve the power saving by up to 69%.

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