Characterization of Power Efficiency of Mobile Video Streaming Services over 4G LTE networks

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***Abstract*—Smartphones and tablets have become the devices of choice for connecting to the internet and watching videos. Video data contributes to the bulk of internet traffic and the number, length and variety of videos have increased significantly. Mobile devices live on limited battery energy which is still a major bottleneck and a source of user dissatisfaction while watching videos. Radio energy contributes to as much as 40% of the overall energy consumed by the device for many video streaming applications. Thus a better understanding of energy efficiency of various streaming protocols and applications, used today, is needed for future design of more energy efficient protocols for video streaming over cellular networks. In this paper we perform one of the first exhaustive characterization of the power efficiency of popular mobile video streaming services such as *YouTube*, *Netflix* and *hulu*, over LTE under various scenarios and user interactions. We evaluate the energy efficiency of streaming policies like adaptive bit rate and chunking and identify the optimal streaming policy for cellular-friendly video streaming.**

I. Introduction

Video content constitutes a dominant fraction in internet traffic today. Trends show that this is prone to increase in the next few years [1]. Users prefer mobile devices for video streaming [1], fueled by the increased throughput and reduced latency of mobile networks (LTE performs similar to Wi-Fi [6]). Moreover, the cost of content delivery is also reducing due to ease of manageability and increased return of investment. As a result, many video content providers are increasing their mobile footprint in the recent years (e.g. Netflix, Youtube, Hulu). They follow a subscription based cost model and in order to improve user engagement, they provide more attention towards optimizing user experience. The video streaming services adapt video delivery according to the client device and network conditions by adapting the bit rate of the content sent to the client and delivering the content in smaller chunks. More preference is given to HTTP than specialized video streaming protocols due to its ease of adaptability in practice. DASH is a popular protocol used by video content providers to adapt bit rate of the video used by the client. Despite many such efforts, a common case of user frustration is the battery drain while watching videos and it is more pronounced in LTE owing to the cellular radio interface.

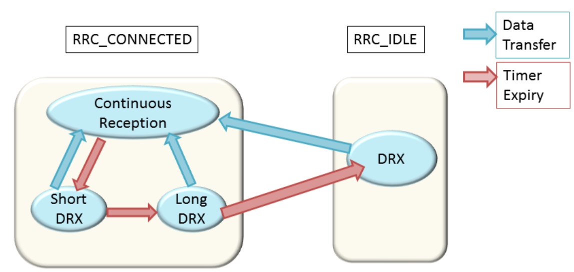

Fig. 1. RRC states in LTE

In LTE networks, the Radio Resource Control (RRC) state machine [6] critically impacts the performance and power consumptions of aplications. Various inactivity timers are used by network operators for saving radio power consumption by trading-off packet latency. Figure 1 shows the RRC states in LTE. LTE has two RRC states - RRC_CONNECTED and RRC_IDLE depending on whether data is being transferred or not. The RRC_CONNECTED state has power conserving states including Short and Long DRX. In the DRX states the radio periodically polls the network for data and is idle otherwise. But the power consumed in the DRX states are still higher than that in the RRC_IDLE state. Applications should intelligently schedule data transfer to obtain the best possible performance, energy and cost savings.

Given the advent of LTE, designing cellular-friendly applications has become ever more critical. In this front, application design should incorporate best practices to improve user experience, energy efficiency and reduce data cost. In video streaming applications, user experience is measured by metrics like join time (time before initial video frame is rendered), playback time (total time for video playback) determined by the buffering ratio. On one hand for better user experience, application should limit the playback time by buffering aggressively. On the other hand, to save on the cost of data transfer, the application should buffer rather cautiously. Further, optimizing energy consumption requires in-depth understanding of the interaction of the application with the RRC state machine. While the popular video streaming services aim at improving user experience, there is very little focus on improving their energy efficiency. It is not clear whether the design approaches taken by popular video streaming services like adaptive bit rate and chunking provide energy savings without taking into consideration the RRC state transitions.

Our contributions in this paper are outlined below.

- As per our knowledge, we perform one of the first exhaustive studies that characterize the performance and energy efficiency of popular video streaming services under various scenarios and user interactions. Such a study is especially important and relavant in the context of mobile networks LTE inorder to understand the trade-offs in designing cellular-friendly streaming services.
- We model the power characteristics of various streaming policies like adaptive bit rate and chunking, and identify the optimal streaming policy for a more efficient streaming experience in LTE.

II. Related Work

A lot of research has been done in improving the power efficiency of mobile and hand-held devices. Different schemes target different features of the device for power reduction. These include network, architecture level, circuit, and software level optimizations. [9] explores a combination of these optimizations for achieving power efficiency. Some recent literature like [11], [12] also confirm the theory that transmitting video frames in bursts actually save significant amount of energy. A very recent work [4] uses battery aware rate adaptation and base station reconfiguration to achieve power savings. An interesting work which effectively schedules data transfers in return for energy savings is [2]. There are also studies which try to look at the energy consumption of web based applications in smartphones. Huang et al.,[**?**] investigate the energy usage in 3G, LTE and WiFi networks and perform case studies of several popular applications on Android in LTE and identify that performance bottlenecks lies less in the network and more in the device's processing power. Huang et al.,[7] conducted an in-depth study of interactions among applications, network transport protocol, and the radio layer and their impact on performance, using a combination of active and passive measurements. They discovered that many TCP connections significantly under-utilize the available bandwidth.This causes data downloads to be longer, and incur additional energy overhead. Deng and Balakrishnan[3] propose a technique to reduce energy consumption by learning the traffic patterns and predicting when a burst of traffic will start or end and then determine when to change the radio's state from Active to Idle, and another to change the radio's state from Idle to Active. Hoque, Siekinnen and Nurminen[5] propose a download scheduling algorithm based on crowd-sourced video viewing statistics which judiciously evaluates the probability of a user interrupting a video viewing in order to perform the right amount of prefetching. They show an energy savings of upto 80%. Li et al.,[8] propose GreenTube, a system that optimizes power consumption for mobile video streaming by judiciously scheduling downloading activities to minimize unnecessary active periods of 3G/4G radio. It achieves this by dynamically managing the downloading cache based on user viewing history and network condition. However the energy crisis is far from over. Our work focuses on a comparative study of power efficiency of video streaming protocols and applications on different wireless networks. There are tools which model the power consumption on smartphones. ARO[10]is such a tool which collects packet traces for streaming applications and pinpoints sources of wasteful data and power drains. It is a widely accepted tool developed by AT&T researchers and we use this for our analysis.

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