Journal of Network and Computer Applications 67 (2016) 118–127

Contents lists available at ScienceDirect

Journal of Network and Computer Applications

journal homepage: www.elsevier.com/locate/jnca

Review

Characterizing power saving for device-to-device browser cache cooperation

Eisa Zarepour [a,*], Abdul Alim Abd Karim [a], Ajay Sharma [a], Mahbub Hassan [a,b], Aruna Seneviratne [b,c]

[a] School of Computer Science and Engineering, University of New South Wales, Sydney, Australia
[b] Network Research Group, National ICT Australia (NICTA), Sydney, Australia
[c] School of Electrical Engineering, University of New South Wales, Sydney, Australia

ARTICLE INFO

Article history:
Received 14 March 2015
Received in revised form
28 October 2015
Accepted 1 January 2016
Available online 18 January 2016

Keywords:
Cooperative caching
Mobile power consumption
D2D communication

ABSTRACT

Internet browsing over cellular networks is a major source of power consumption in mobile devices. A device could potentially reduce its browsing power consumption by downloading a page from the browser cache of a proximate device over the short-range low-power non-cellular device-to-device (D2D) wireless link, such as Bluetooth. Using an Android-based cooperative browser prototype, this paper experimentally characterizes the power saving opportunity of such D2D cache cooperation. In particular, we model the impact of cellular network power management protocol and the dynamic components of web pages on the power saving of D2D cooperation. We find that the power saving is limited (upper bounded) by the power management parameter values of cellular networks, which could vary significantly from operator to operator. Based on previously reported cellular power management data and the data obtained from our own experiments, the upper bound can vary from as low as 15–51%. Our model also shows that the existence of dynamic components in the web page decreases the power saving further proportional to the amount of dynamic components. We validate the model with power measurement data from smartphones using real cellular networks for Internet access and Bluetooth connectivity for D2D cache access. By downloading most popular web pages and studying the distribution of their dynamic components, we find that the expected amount of dynamic component in a popular page is rather small, allowing D2D cooperation to achieve device power saving close to (95% of) its upper bound.

Contents

1. Introduction . . . 119
2. Device power saving model . . . 119
3. Android prototype . . . 120
4. Experiment design . . . 121
   4.1. Mobile device and cellular connectivity . . . 121
   4.2. Power measurement . . . 121
   4.3. Controlled-α experiments . . . 122
   4.4. α Determination of popular web sties . . . 122
5. Experimental results . . . 123
   5.1. 3G and Bluetooth power consumption . . . 123
   5.2. Validation of analytical model . . . 123
   5.3. Distribution of dynamic factor . . . 123
   5.4. Latency and energy . . . 124

* Corresponding author.
E-mail addresses: ezarepour@cse.unsw.edu.au (E. Zarepour), aaak656@cse.unsw.edu.au (A.A. Abd Karim), ajays@cse.unsw.edu.au (A. Sharma), mahbub@cse.unsw.edu.au, mahbub.hassan@nicta.com.au (M. Hassan), aruna.seneviratne@nicta.com.au, a.seneviratne@unsw.edu.au (A. Seneviratne).

http://dx.doi.org/10.1016/j.jnca.2016.01.003
1084-8045/

6. Discussion . . . 124
6.1. Availability . . . 124
6.2. Mobility . . . 124
6.3. Selfishness . . . 124
6.4. Distributed processing . . . 125
7. Related work . . . 125
8. Conclusion . . . 125
Appendix . . . 125
References . . . 126

1. Introduction

Recent studies show that Internet browsing is one of the major sources of energy consumption in mobile devices (Balasubramanian et al., 2009; Thiagarajan et al., 2012). In many situations, such as travelling in a train or bus, cellular networks, such as 3G/LTE, remain the only choice for Internet access for a large number of users. Unfortunately, energy cost of Internet browsing is particularly high when using a cellular network as the mobile has to use high power to communicate with a distant radio tower often without a line-of-sight. With recent standardization efforts, which facilitates low energy high data rate direct device-to-device (D2D) communication, such as Bluetooth Low Energy (LE) (Omre, 2010), WiFi Direct, and LTE Direct (Qualcomm), it becomes attractive to consider cooperative caching and sharing of Internet browsing data between proximate mobile devices to reduce the energy and monitory cost of cellular browsing.

The topic of cooperative caching and data sharing for mobile devices has been studied intensively in the recent years. These works, such as Shen et al. (2005) and Chan et al. (2009), have developed various cooperative cache management models that provide high cache hit rates in proximate devices, especially in crowded places. When combined with emerging D2D standards, these developments suggest that a device trying to access a popular web page will be able to locate the page in a proximate device quickly, power-efficiently, and with high probability. Energy saving comes as a result of the page being transferred over the low energy D2D link instead of being downloaded over a high power cellular link.

While intensive research has been conducted on cooperative caching models to increase hit rates, little has been reported about the potential power saving in practical implementations. Using a practical prototype, this paper attempts to answer the question of how much power saving is possible in cooperative caching systems. We first propose a simple theoretical model to capture the impact of cellular power management protocol and the dynamic components of web pages on the power saving of D2D cooperation. We show that the power saving is limited (upper bounded) by the power management parameter values of cellular networks, which could vary significantly from operator to operator. Our model also shows that the existence of dynamic components in the web page decreases the power saving further proportional to the amount of dynamic components. We validate the model with power measurement data from an Android-based prototype using real cellular networks for Internet access and Bluetooth connectivity for D2D cache access. By examining most popular web pages and studying the distribution of their dynamic components, we find that the expected amount of dynamic component in popular pages is rather small, allowing D2D cooperation to achieve power saving close to (95% of) its upper bound.

The rest of the paper is organized as follows. Section 2 presents the proposed device power saving model to study power consumption of cooperative caching as a function of cellular parameters and dynamic page factor. We explain our Android prototype in Section 3 followed by experimental methodology in Section 4. Empirical results are analyzed in Section 5. We discuss few issues that might potentially affect the performance of cooperative caching in Section 6. We review related works in Section 7 before concluding the paper in Section 8.

2. Device power saving model

The purpose of this section is to provide a theoretical model to approximate the expected device power saving brought by D2D cooperation in the presence of 3G/LTE radio resource control (RRC) protocol (Deng and Balakrishnan, 2012) and dynamic page components. Our model builds on the power characterization of 3G/LTE RRC protocol previously reported (Balasubramanian et al., 2009; Deng and Balakrishnan, 2012) in the literature. These studies confirm that in ACTIVE state, i.e., when the device is allocated a dedicated channel by the base station, 3G/LTE radio consumes high power during transmission of data (called P_{3GA} in this paper), but less power when it is not transmitting data (called P_{3GT} in this paper[1]). The amount $P_{3GA}-P_{3GT}$ is an important parameter used in our model. There are even lower power states, namely IDLE states, for the 3G/LTE radio, but the radio switches to one of them only if the device does not transmit any data for a long time (a few seconds to tens of seconds) when it is in ACTIVE state. We do not consider these IDLE states in our model, because we seek to approximate power consumption behavior only during a page download, where many components are downloaded one after the other without any gap.

The system model consists of two mobile devices each equipped with a 3G/LTE and a short-range (SR) D2D interface. The mobiles communicate with the cellular base station using the 3G/LTE interface, but uses the SR interface to communicate between them. For power consumption modelling, we consider power consumption from the moment that a device (*Donee*) has found a Donor that has recently downloaded the page from 3G/LTE. The page has multiple components, some of which are static, i.e., do not change, while others are dynamic and must be re-downloaded from the Internet. The fraction of the page which is dynamic is referred to as the dynamic factor (α). Based on Bluetooth power characterization (Cano et al., 2007), which says that the transmitting device consumes significantly more power than the receiving device, we consider asymmetric power consumption of the short-range radio between the *Donor* and the *Donee*. We use the following notations:

- P_S^r: power consumption of the SR radio in the Donor device.
- P_S^e: power consumption of the SR radio in the *Donee* device.

[1] Any non-negligible power consumption by 3G/LTE when no data is being transmitted is often referred to as the 'tail' power in the literature (Deng and Balakrishnan, 2012; Gupta et al., 2013).