Pervasive and Mobile Computing 10 (2014) 3–21

Contents lists available at ScienceDirect

Pervasive and Mobile Computing

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

Smartphone sensing offloading for efficiently supporting social sensing applications

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ARTICLE INFO

Article history:
Available online 31 October 2013

Keywords:
Energy efficiency
Phone sensing
Sensing offloading
Smartphones
Social sensing

ABSTRACT

Mobile phones play a pivotal role in supporting ubiquitous and unobtrusive sensing of human activities. However, maintaining a highly accurate record of a user's behavior throughout the day imposes significant energy demands on the phone's battery. In this work, we investigate a new approach that can lead to significant energy savings for mobile applications that require continuous sensing of social activities. This is achieved by opportunistically offloading sensing to sensors embedded in the environment, leveraging sensing that may be available in typical modern buildings (e.g., room occupancy sensors, RFID access control systems).

In this article, we present the design, implementation, and evaluation of *METIS*: an adaptive mobile sensing platform that efficiently supports social sensing applications. The platform implements a novel sensor task distribution scheme that dynamically decides whether to perform sensing on the phone or in the infrastructure, considering the energy consumption, accuracy, and mobility patterns of the user. By comparing the sensing distribution scheme with sensing performed solely on the phone or exclusively on the fixed remote sensors, we show, through benchmarks using real traces, that the opportunistic sensing distribution achieves over 60% and 40% energy savings, respectively. This is confirmed through a real world deployment in an office environment for over a month: we developed a social application over our frameworks, that is able to infer the collaborations and meetings of the users. In this setting the system preserves over 35% more battery life over pure phone sensing.

1. Introduction

The proliferation of smartphones with sensing capabilities has created an opportunity to design systems that capture vast amounts of information about people's social behavior. By leveraging the device's sensing and communication capabilities, applications can capture an accurate depiction of the user's social context, which enables the design of novel applications that can enhance the user experience [1], improve productivity [2], or facilitate new business opportunities such as targeted advertisements [3]. It is expected that the next generation of mobile applications will use continuous sensing of social context at an extremely fine granularity.

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1574-1192/$ – see front matter
http://dx.doi.org/10.1016/j.pmcj.2013.10.005

A major challenge in achieving accurate social sensing is the significant impact that continuous sensing has on the phone's battery life. The detection of social context through mobile phone sensing, typically leverages a wide range of sensing modalities. Systems such as CenceMe [1], or EmotionSense [4], utilize a combination of accelerometer, Bluetooth, location, and microphone, in order to characterize a particular social situation. The significant energy cost of collecting such information reduces the phone's battery life, and hinders the wider adoption of such applications. Existing efforts to minimize the energy impact rely primarily on adaptive sensing techniques, trading off energy for accuracy with the aim of reducing unnecessary sensor sampling on the device [4,5]. Recently the mobile phone industry made some steps in designing devices that are more suitable for continuous sensing. The latest Apple iPhone 5S,[1] as well as Motorola Moto X[2] feature dedicated chips for continuous activity and audio sensing. The aim of these designs is to reduce the impact of using a power hungry processor to perform sensor sampling, by incorporating a low power micro-controller for such tasks. A multi-processor architecture that divides the computation between a low power processor and the phone's main processor to support a speaker recognition system is presented in [6]. These hardware architectures offer more flexibility for the design of energy efficient continuous sensing applications. However, there is still a significant energy cost for supporting continuous sensing on mobile devices, especially when considering energy demanding sensing activities, such as speech recognition, or location tracking. Although techniques such as adaptive sampling and dedicated context processors have shown improvements in terms of energy consumption, there is still a need for more efficient and complementary solutions that can significantly reduce the cost of continuous sensing before such applications can be widely accepted by everyday users.

In this work, we introduce a novel approach that can offer significantly bigger reductions in energy cost without compromising on the accuracy, by *opportunistically offloading sensing to fixed sensors embedded in the environment*. Most modern buildings are instrumented with a variety of sensors, such as RFID access control systems, Passive Infrared sensors, light sensors, etc. Intuitively, if a mobile application can take advantage of such sensing infrastructures, it could at times suspend local phone sensing, by leveraging remote sensors. For example, relying on a building's access control system, a mobile application can decide to suspend any localization mechanisms on the phone while the user remains in the same building or even room. The feasibility of this approach and the massive energy gains that can be achieved have significant implications both for the design of future mobile applications, and the deployment of sensing infrastructures within smart-buildings. Indeed, such an approach imposes a strong argument for the need of sensing infrastructures that support open access by third party systems, enabling a wide range of mobile and pervasive applications.

In this work, we explore the feasibility of efficient sensing offloading by considering the requirements of social sensing applications operating within a smart-building environment. Through an experimental study within our research institution we demonstrate that the benefits of sensing offloading can only be achieved by considering the potential gain of offloading a particular sensing task versus the potential energy cost incurred primarily due to network communication. Estimating both metrics can depend on a number of parameters and most significantly the behavior of the user and their peers. In this paper, we present the design, implementation, and evaluation of METIS, a sensing platform that implements a novel adaptive sensing distribution scheme that automatically distributes the sensing tasks between the local phone and sensing infrastructure sensors in order to support accurate continuous sensing of social activities. The proposed scheme considers various parameters such as the mobility pattern of the user, duty cycling interval, and cost of sensing to determine whether sensing offload can result in energy gain at any given situation. We show through benchmarks using real traces that the sensing distribution scheme achieves over 60% and 40% energy savings compared to static scenarios where only phone-based sensing is used, and only remote sensors are used, respectively.

Finally, we evaluate the system through a real deployment with 11 users for a month in a working environment using *WorkSense*, a social application that utilizes METIS and aims to raise awareness and improve visibility of social interactions at the workplace, by tracking formal and informal meetings during daily routines, and inferring how social interactions may impact the user's performance. The deployment shows that the application is able to infer the effect of various interaction and social patterns on the work of the users. Furthermore, we show that the system extends battery life by more than 35% compared to when no sensing offloading to the infrastructure is used.

The remainder of this article is organized as follows: In Section 2, we present a study that we conducted to understand the feasibility of the sensing offloading. We then present the design of the METIS system in Section 3 followed by several benchmark tests in Section 4. We present the WorkSense application, and an evaluation of the METIS system and the WorkSense application using a real deployment in Section 5. We present the related work in Section 6, and finally, conclude the paper in Section 7.

2. Saving energy through sensing offloading

The idea of sensing offloading is built on the vision of mobile phone users living in an environment instrumented with a range of sensors that can be accessed over the internet. Within such environment certain pieces of information can potentially be sensed through either the user's mobile device or a sensor that is embedded in the environment. For

1 http://www.apple.com/iphone-5s/specs.
2 http://www.motorola.com/us/FLEXR1-1/moto-x-specifications.html.