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Energy efficient indoor tracking on smartphones

Dezhong Yao [a,b], Chen Yu [a,*], Anind K. Dey [b], Christian Koehler [b], Geyong Min [c], Laurence T. Yang [a], Hai Jin [a]

[a] Services Computing Technology and System Lab, Cluster and Grid Computing Lab, School of Computer Science and Technology, Huazhong University of Science and Technology, Wuhan, 430074, China

[b] Carnegie Mellon University, Pittsburgh, 15217, United States

[c] School of Informatics, University of Bradford, Bradford, BD7 1DP, UK

HIGHLIGHTS

- We profile the energy consumption of different computing and communication use cases.
- An accelerometer-based method for adaptively managing the use of the WiFi adapter is proposed.
- We propose a sensor management strategy for adaptive duty cycling and a data upload strategy for indoor situations.

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ABSTRACT

Continuously identifying a user's location context provides new opportunities to understand daily life and human behavior. Indoor location systems have been mainly based on WiFi infrastructures which consume a great deal of energy mostly due to keeping the user's WiFi device connected to the infrastructure and network communication, limiting the overall time when a user can be tracked. Particularly such tracking systems on battery-limited mobile devices must be energy-efficient to limit the impact on the experience of using a phone. Recently, there have been a lot of studies of energy-efficient positioning systems, but these have focused on outdoor positioning technologies. In this paper, we propose a novel indoor tracking framework that intelligently determines the location sampling rate and the frequency of network communication, to optimize the accuracy of the location data while being energy-efficient at the same time. This framework leverages an accelerometer, widely available on everyday smartphones, to reduce the duty cycle and the network communication frequency when a tracked user is moving slowly or not at all. Our framework can work for 14 h without charging, supporting applications that require this location information without affecting user experience.

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1. Introduction

Many useful applications require long-term, high-accuracy tracking of the location of their users while indoors. These include wayfinding applications for people with disabilities [1–3], indoor monitoring of elders [4], locating people in emergency response situations, augmented reality and point-of-sale applications. However, the most accurate indoor tracking systems require infrastructure to be purchased and deployed, and for users to wear tags or beacons [5,6]. Instead, researchers are relying on infrastructure that is already commonly available: WiFi networks with multiple access points and WiFi-enabled smart phones carried by users. While there are many interesting issues to be addressed in improving the accuracy of localization with such systems, here we focus on how to improve their energy-efficiency. Many applications require real-time tracking and/or long-term history, which necessitates energy-efficient localization. But the WiFi adapter on smart phones consumes a lot of energy, limiting the usage time of mobile devices [7]. There are two types of long-term tracking applications: One type is applications that may not need a high sampling rate and data communication frequency, such as wayfinding applications. The other type is applications that need a high sampling rate, like emergency tracking systems. Current studies do not provide models or algorithms for finding the optimal sampling rate and data communication frequency for different types of applications.

The main goal of this paper is to build an energy-efficient localization framework that automatically manages sensor availability, accuracy and energy. There is an important tradeoff between localization accuracy in indoor environment and battery lifetime. For wayfinding and health monitoring applications, they need the longest battery lifetime possible and do not require the highest accuracy. Some navigation systems need to have high accuracy, but

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[*] Corresponding author. Tel.: +86 2787541924x8023.
E-mail addresses: yuchen@hust.edu.cn, hust.yuchen@gmail.com (C. Yu).

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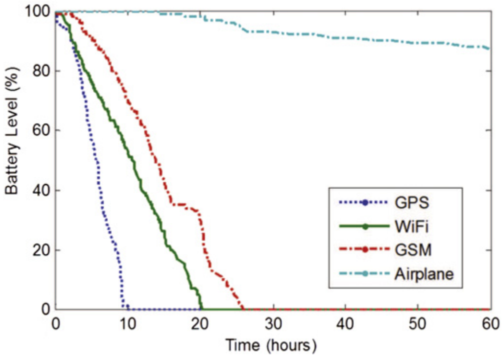

Fig. 1. Energy consumption comparison.

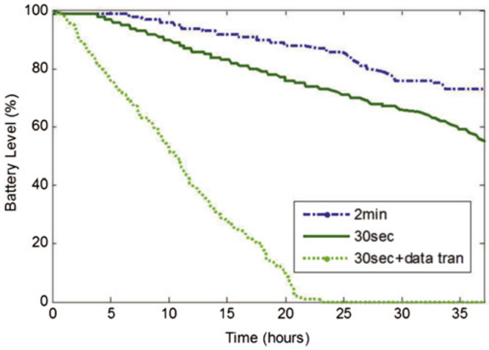

Fig. 2. Sensing interval comparison for WiFi.

are not very concerned with energy consumption as they are often not used for a long period of time. For our daily tracking applications, we need to build a model to extend the battery life as long as possible, while also dynamically meeting the accuracy goal at the same time. From a user experience perspective, this model needs to allow the system to optimize battery life by intelligently managing the location accuracy and energy trade-offs based on available sensors. To realize the above goal, we developed an approach based on two observations. First, location applications do not always need the highest available accuracy, such as when people are standing in one spot for a long time or going down or up stairs. Second, a phone has multiple modalities to sense indoor location aside: WiFi triangulation [8,9], cell-tower triangulation [10], Bluetooth vicinity, audio-visual sensing [11], accelerometer sensing. Those modalities can be selected to efficiently meet the location needs at lower energy costs. In another part, we can use energy prediction method [12,13] to calculate how much energy will be used in the next few minutes based on current motions of a user.

To explore the framework, we first use a modular approach to build a WiFi-based indoor location system based on the Android platform and an existing Wifi infrastructure. Then, a detailed measurement study is conducted to quantify the energy consumed by the different modules. We compare the energy costs of localization when running a localization algorithm locally on the mobile device and on the remote server. We find that energy consumption is intimately related to the data transmission time and scan frequency of the WiFi adapter. Executing the location algorithm locally on the smart phone minimizes the use of the WiFi adapter, and thus produces the most energy-efficient results.

The work presented in this paper makes the following contributions: (1) we profile the energy consumption of different computing and communication use cases to design an energy-efficient indoor tracking framework; (2) we propose an accelerometer-based method for recognizing a user's movement status for adaptively managing the use of the WiFi adapter; (3) we propose a sensor management strategy for adaptive duty cycling and a data upload strategy for indoor situations; (4) we demonstrate that the framework, with the proposed strategies, can be implemented on the Android platform with a battery life of 14 h in the presence of regular phone usage, an improvement of 4 h over a static duty cycle approach. The evaluation results show our framework can handle different activity modes, *e.g.*, standing, walking, going upstairs/downstairs. Furthermore, it can support whole day indoor tracking without a significant impact on a smart phone's battery life.

The rest of the paper is organized as follows: The challenges of indoor energy-efficient tracking are explained in Section 2. The related work is also summarized in Section 2. In Section 3, we present the detailed design of our framework. Section 4 describes the framework architecture and our implementation method including the implementation of the motion monitor. The framework's performance is evaluated in Section 5. Finally, Section 6 concludes with a discussion of our experiments and framework.

2. Motivation

In this section, we motivate the work by highlighting the results from a set of experimental evaluations. We describe the factors impacting energy efficiency in indoor location sensing through an initial experiment with Android smart phones and summarize the limitations of existing outdoor energy-efficient location-sensing approaches.

2.1. *Energy hungry device: WiFi adapter*

We first estimate the impact of using the power intensive WiFi adapter on smart phones. By considering a scenario where a user is working in a building with a location tracking application (LTA) running. The application determines the user's current location in a timely manner using the Android location API. The battery usage level is measured using the Android power API. For comparison, we run the same LTA on the same phone in 4 different settings: in airplane mode, WiFi only, cellular network only, and GPS only. The location refresh rate is set to 30 s and each experimental setting is stopped when the phone turns itself off due to the battery dying.

Fig. 1 depicts the battery level of the phone for each experimental setting. As shown in Fig. 1, GPS consumes more power than the other localization technologies. Using WiFi and GSM, the location tracking application can work for more than 20 h without other activities. WiFi and GSM signals are commonly available in indoor locations. But these methods also use too much energy when the location application is continuously running, limiting the use of other applications.

2.2. *Data transform compression*

WiFi has two main energy consuming components: (1) scanning and associating to an access point (AP) and (2) transferring data [14]. We conduct experiments to understand the relative impact of these aspects. Consider two conditions for a location tracking application (LTA) that uses WiFi-based location. In the first condition, it only samples the WiFi signal strength with a scan interval of 30 s, but does not transmit any data. The second condition is the same as the first, but it also transmits data to a server, by having the WiFi adapter connect to an AP. We can see the impact on battery lifetime of these two conditions in Fig. 2. The energy consumed by data transmission is nearly five times than that of the scan and association. Other work has shown that transmitting larger amounts of data does not consume significantly more

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