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Energy-efficient automatic location-triggered applications on smartphones

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ABSTRACT

With the prevalence of localization techniques in smartphones, location-based applications on mobiles have become increasingly popular. However, only minorities of applications can be triggered automatically by the predefined locations of interest without any human interaction. One reason is that the inevitable operation of location detection by GPS is power-intensive. While existing work has focused on energy efficiency in continuous location tracking, energy-efficient location detection for matching predefined location of interest remains to be further explored. This paper proposes a unified framework that supports energy-efficient location detection for automatic location-triggered applications. Our framework triggers desired events only when the user is approaching the predefined locations of interest. Besides the efforts we make to reduce the number of GPS updates by cooperating with other types of on-device sensors, the framework also aims to coordinate multiple location-triggered applications to further reduce energy consumption on location updates. We implemented our framework as a middleware in the Android operating system and conducted extensive real experiments. The experimental results demonstrate that our framework can reduce the number of GPS requests and low the energy consumption of the smartphones significantly.

1. Introduction

With the popularity of mobile Internet, people have exploded intelligent mobile services and innovative applications on smartphones. The convenience of the handheld equipment and powerful functions of the sensors on device also brings the new era of the localization applications in our daily life. The usages of location-based applications (LBAs) are generally categorized into venues check-in [1], social connection [2] and local information exploration [3,4]. Several applications are trying to combine localization, mobility and social network into one integrated service solution [5]. Nevertheless, the increasing computation capability of smartphones has drastically reduced the lifetimes of the devices. Designing mobile applications is no longer just about perfecting its computing power, communication, and user interface, but about providing all these functions with less power. Most smartphones contain Bluetooth, Wi-Fi, and GPS radios inside, and in many instances these components operate simultaneously. The GPS radio, in particular, is a notorious battery killer. You can see the battery bar getting shorter as you run your navigation application. Development of energy-efficient LBAs is important to prolong the lifetime of smartphones and maintain a green network for a sustainable society.

There exists a few popular and successful location-trigger applications in either Android or iOS platform. The applications need information about a user's current position to provide better services, such as uploading data and fetching available service nearby. However, the power-intensive GPS sensor reduces the phone's battery life to less than nine hours [6,7]. In order to save energy, it turns out to be the user's responsibility to launch the application at location of interests. This will arouse problem if a user fails to start the application because of individual reasons or surrounded circumstance, such as in disaster scenarios like earthquake. Therefore our work tends to introduce a unified framework for designing energy-efficient and automatic location-triggered applications.

One motivation for us to research on location-triggered application design is that there are many LBAs in the market, but very few of them are based on automatic location detection to trigger actions. Most of the existing location based applications adopt naïve GPS updates. Other applications rely on WiFi and cell towers for localization, but they can only support urban areas that are fully covered by WiFi and cellular networks. For example, a very popular

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location-triggered application, called Llama [8], supports users only in populated areas with full cellular tower coverage for localization. Nowadays, almost every smartphone has GPS module, but it has huge energy concern. Can we support location-triggered tasks energy-efficiently with on-device GPS when people are in the suburbs? This motivates us to focus more on the GPS performance and its energy saving issue in this paper.

Considering the diversified information and possible services associated with locations, it is crucial to be able to trigger services automatically on the mobile phones with minimum human interference. To achieve this, the mobile application needs to maintain and keep track of the actions that it wants to perform at predefined locations. Location-triggered applications for smartphones ought to maintain database for storing locations of interest and their associated actions. We need an energy-efficient and adaptive scheme when coming to using GPS to detect if the device is at any of the locations of interest, and such framework should be independent from the specific business needs, i.e., different customized actions from different applications we see in the markets.

In addition, energy efficiency is a major concern for mobile devices. Although many approaches that are only related to the smartphones' intrinsic properties have been proposed to trade-off accuracy with energy consumption, like using accelerometer to estimate movements [9,10], the calculations are not targeted for locating predefined locations as destinations when scheduling the sensors in mobile phones. This motivates us to delve deeper in energy efficiency for mobile location-trigger applications. By taking the advantage of geometrical composition of destinations in the map, we investigate intelligent sensor scheduling to duty-cycle GPS for saving energy.

Another inevitable motivation for the research comes from the fact that almost no application keeps its eye on the power-intensive sensing behaviors from other simultaneously running applications on the same device. Without a doubt, it will arouse the problem of redundant GPS request, when one application requests location update with GPS in its own business flow and only 10 s later, another application requests location update with GPS again. Obviously the user is still at the same place but the expensive price for the second GPS calling has been paid. From a business implementation perspective, it is not necessary and expensive to monitor other applications' behavior. Programmers from different companies need only focus on their individual business and the users will just need to set up their private preferences. Therefore we need to investigate how to design the framework as one middleware to support multiple location-triggered applications installed on the same phone to benefit from each other for energy concern.

Our work in this paper makes the following contributions: (1) we present a unified framework to support location-triggered service by maintaining the geo-fenced areas of interest with associated actions. (2) We propose an energy-efficient approach that intelligently duty-cycles GPS to detect locations. The principle is to trade-off accuracy for energy efficiency by location estimations and multiple sensors scheduling. (3) We extend the framework further to coordinate multiple location-triggered applications with different business flows to achieve the same energy efficiency goal. (4) We implemented our proposed framework on Android smartphones for experiments in real-world applications. The results demonstrate that the proposed approach used in location-triggered scenarios could greatly reduce the usage of GPS for location updates.

2. Related work

Localization and trajectory tracking have attracted much research attention for location-based services for mobile devices. The simplest implementation is for the mobile devices to fetch the GPS readings and report them to the server. The request of GPS readings can be done periodically by the clients or upon request from the server [11]. Unfortunately, making frequent GPS requests can consume a lot of energy on the mobiles. Different from existing research on distance calculation for moving object and target [12,13], our work takes the advantage of utilizing alternative and more light-weight sensors to perform localization. It also considers the coordination among multiple location-triggered applications.

Technologies like Wi-Fi, cell-tower triangulation [14], Bluetooth [10] have been considered as alternatives to GPS when it comes to designing proactive energy-efficient LBS. WiFi and GSM can last as long as 40 and 60 h [15] compared to GPS request. Such solutions usually have clear constraints that the network should be available all the time. Dhondge et al. [16] proposes the system that facilitates mobile devices with estimated locations using WiFi in cooperation with a few available GPS broadcasting devices. SensLoc [17] also investigated localization techniques based on WiFi and GSM to improve battery life in expense of localization accuracy. Bareth [18] researches location-triggered concepts as we do by proposing the reverse cellular positioning architecture and WiFi to detect fine-grained target areas. Even though it is the closest research to our work from the perspective of spatial relation between a user and a target, the system cannot work without the support from cell tower.

Recently the newly developed "proximity beacons" from Qualcomm [19] and iBeacon from Apple [20] have drawn enormous attention due to their energy-efficient solutions that are based on Bluetooth. However, compared with the existing location-based applications, there are still barriers to make the beacon technology widely adopted today. Firstly, the beacon technology is specifically designed for indoor micro-location monitoring scenarios, such as in a big shopping mall. It requires installation of extra hardware (e.g. the "proximity beacons" from Qualcomm) to be installed at predefined locations. They are usually being attached to the walls or ceilings to transmit signals via Bluetooth connection. When Bob wants to be reminded to buy milk when passing by a small grocery store, or to fetch his ironed suit when passing by another small local clothing store on his way home, he must make sure his places of interest all have beacons installed. In such common scenarios, beacon applications are not only less convenient than most LBAs on the end-user devices, but also face the practical hurdles for wide adoption. Secondly, even some specific iOS devices that support Bluetooth Low Energy can be turned into an iBeacon [20], they always requires the user to turn on Bluetooth and establish connection with the beacon through a specified application. It might decrease the usability in many scenarios. In addition, the security-oriented approach does not necessarily protect the privacy of users. For example, the user may expose his physical locations to beacons of external parties, while his locations could actually be obtained by the GPS on his mobile phone privately. Thirdly, existing beacon applications are generally not supporting Android. A study from International Data Corporation (IDC) discovered that Android dominates 81% of world smartphone market during the third quarter of 2013 [21]. With the popularity of Android smartphones, there is a gap for beacon technology to bridge as it has been developed mainly based on iOS. For example, the proximity features from Qualcomm are only available on iOS [19]. Similarly, the iBeacon technology is only available on specific iOS devices [20].

Mobility studies of the mobile users have also been introduced to meet the needs of proactive position tracking to save energy. Ryder et al. concentrated on contextual information collection and mobility prediction using decision model [6]. Chon et al. [22] proposed a Markov decision process-based adaptive duty cycling