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Fast track article

A novel localization and coverage framework for real-time participatory urban monitoring

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ABSTRACT

Participatory sensing is a powerful paradigm in which users participate in the sensing campaign by collecting and crowdsourcing fine-grained information and opinions about events of interest (such as weather or environment monitoring, traffic conditions or accidents, crime scenes, emergency response, healthcare and wellness management), thus leading to actionable inferences and decisions. Based on the nature of user involvement, participatory sensing applications can be of two types—automated and user manipulated. The first type of applications automatically collects data samples from smartphone sensors and sends them to the server. On the other hand, the second type of applications depends on the users to manually collect data samples and upload them at their convenience. Because of the high density of smartphone users in urban population and ease of participation, the automated participatory sensing paradigm can be effectively applied to continuous monitoring of various phenomena in urban scenarios (e.g., fine-grained temperature monitoring, noise or air pollution), leading to what is called participatory urban sensing. However, for creating a fine-grained and real-time map of the monitored area, the data samples need to be collected continuously (at a high frequency) which poses several research challenges. First, how to ensure coverage of the collected data that reflects how well the targeted area is monitored? Second, how to localize the smartphones since continuous usage of the location sensor (e.g., GPS) can drain the battery in few hours? Third, how to provide energy efficiency in the data collection process by collecting necessary data samples in each data collection round? In this article, we propose a novel framework called PLUS to address three major issues in real-time participatory urban monitoring applications, namely, ensuring coverage of the collected data, localization of the participating smartphones, and overall energy efficiency of the data collection process. Specifically the PLUS framework can guarantee a specified requirement of partial data coverage of the monitored area in an energy efficient manner. Additionally we devised a Markov-Predictor based energy efficient outdoor localization scheme for the mobile devices to participate in the data collection process. Simulation studies and real life experiments exhibit that PLUS can significantly reduce energy consumption of the mobile devices for urban monitoring applications as compared to traditional approaches.

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1. Introduction

Over the last decade, we have witnessed tremendous advancement in the smartphone technology. Mobile phone has evolved from basic communication device to a powerful sensing platform with a rich set of built in sensors. Examples include microphone for capturing audio, camera for capturing video, RGB light sensor for measuring intensity of light, gesture sensor for detecting hand movement, Global Positioning System (GPS) for retrieving location, barometer for measuring atmospheric pressure, accelerometer for measuring acceleration, gyro sensor for determining rotation state of the device, fingerprint sensor for identifying user fingerprint, pulse sensor for monitoring heart rate, and so on. Moreover, modern smartphones provide convenient interfaces (e.g., Bluetooth, WiFi, NFC) to connect with external sensors and devices, hence giving birth to a host of wearable gears such as Apple Watch [1], Samsung Gear [2], iHealth Edge [3], etc., which stay connected with the smartphones while monitoring various phenomena surrounding the user. As a result, a new paradigm of applications exploiting the sensing platform of the mobile devices emerged in the last decade and gained significant attention both in the industry and research community.

Due to the ubiquitous nature of smartphone and its extremely large user base, it has been leveraged to design applications in different domains of our life. For example, applications were designed where the smartphone sensors are used for assisting and monitoring individuals, such as activity, sleep, and overall health and well-being monitoring [4–6]. By taking it a step further, data collected from individuals can be compiled by healthcare providers or government agencies and associated with environmental factors to analyze not only individual but also community-wide activity, habit and exposure [7]. Another important class of applications aims to monitor different environmental and urban scenarios by collecting data from the smartphone sensors. Similar to monitoring environmental or urban scenarios with Wireless Sensor Networks (WSNs), a network of smartphones can be conceived for such tasks where a smartphone is treated as a location-aware multi-modal sensor node, and participates in the data collection process by sampling the required sensor. The notion of sensory data collection through the participation of a group of smartphone users to create knowledge is known as *participatory sensing* [8–12] in general.

Depending on the use case, there are several design choices for a participatory sensing application. For example, based on the feature to monitor, it can be designed for monitoring urban/environmental feature or personal (smartphone user's) scenario. Based on user involvement for data collection, an application may notify the user each time to collect data sample, whereas, an application can be designed to automatically collect data samples as required, once authorized by the user. Some application can be designed for monitoring only indoor events, while some other may target outdoor scenarios. Based on the activity or motion state of the smartphone user, there can be variations too—some application can be designed to collect data samples from pedestrians, while some other may collect data from smartphone users moving in vehicle. Finally, based on the update frequency requirement of the underlying monitored phenomenon, an application could be designed to collect data continuously or at a much lower frequency. Adopting each of these design choices poses its own research challenges that must be solved for successful deployment of a participatory sensing application. In our work, we primarily address the challenges of participatory sensing applications designed for monitoring urban scenarios automatically and continuously, also referred as real-time participatory urban monitoring application.

One important challenge in the data collection process is how to ensure the coverage of the collected data? For traditional Wireless Sensor Networks (WSNs), this problem has been extensively investigated where sensors are either static and deployed in a known area, or moving with predefined trajectories [13–17]. Hence, sensors in WSNs can be scheduled to collect data samples as required to achieve the coverage. In case of participatory sensing applications, data collection is performed by mobile devices (smartphones) carried by human users with uncontrolled mobility. Another important challenge is the localization of the smartphones especially when the location information is required continuously. And lastly an important challenge is to ensure energy efficiency in the data collection process. For WSNs, energy efficiency in the data collection process has been widely investigated from different aspects [18–21]. Similar to wireless sensors, the mobile devices are battery powered and hence energy efficiency in the data collection process is also very important [22–24]. The existing approaches that address these challenges broadly fall into two categories. In the first category, the server collects data samples from all participating mobile devices at a predefined frequency (as low as 1 s) [25], resulting in redundant data sample collection from densely populated urban area. In the second category, each participant informs its location to the server. In turn, the server selects the mobile devices as required to ensure different criteria (e.g., coverage, battery life, etc.) [26,23]. However, for a real-time continuous monitoring applications by pedestrians, location needs to be frequently updated and informed to the server, which can take significant amount of battery life.

In this paper, we propose a novel framework called *Energy Efficient Framework for Localization and Coverage in Participatory Urban Sensing* (PLUS) [27], where a mobile device is not required to send its location information to the server. PLUS divides the monitored area into smaller blocks, and uses a metric called *desired sensing coverage (DSC)* [28], to ensure partial coverage of the collected data associated with each block. A participating mobile device executes a novel energy efficient localization scheme to determine the block level location (i.e., the block where a user currently is) of the user. The sLoc scheme maintains individual mobility history and uses a Markov Predictor Model to predict his future block transitions (i.e., the block where the user is likely to move from the current block). Moreover, to activate the GPS effectively to determine a block transition, sLoc learns from previous behavior of the user in each block. After determining the block level location, a mobile device probabilistically performs the sensing task and sends the collected data to the server to ensure the DSC requirement. The major contributions of this paper can be summarized as follows.