Crowdsensing Traces Using Bluetooth Low Energy (BLE) Proximity Tags

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Abstract
Designing massive scale crowdsensing experiments using smartphones can be very challenging. In this work, we define a new approach for designing massive crowdsensing applications where we offload the burden of sensing from smartphones to low cost off-the-shelf Bluetooth Low Energy (BLE) proximity tags. We discuss the usage of advertisements in BLE tags as a new energy-efficient sensing resource for massive scale crowd mobility trace collection. We performed a large experimental deployment with 600 tags and 10 smartphones conducted during the 5 days of the world largest annual gathering (The Hajj). We were able to achieve ~90% detectability rate while effectively reconstructing the routes of the participants.

Author Keywords
Bluetooth Low Energy; Proximity; Crowdsensing; Route Reconstruction

ACM Classification Keywords
C.2.1 [Computer Systems Organization]: Computer Communication Networks–Wireless communication; C.3 [Computer Systems Organization]: Special-Purpose and Application-Based Systems

Introduction

The proliferation of sensor-rich smartphones and their inherent mobility enables a new and fast-growing sensing paradigm referred to as crowdsensing. Crowdsensing [4] can be very useful approach for performing mobility patterns and crowd behaviour studies since detailed traces of users can be collected. However, in such massive scale crowdsensing applications, using smartphones as the main source of sensor data is very challenging due to 1) the need for downloading and installing a data collection application on the participant's smartphone. 2) The extra burden on the resource constrained smartphones in terms of energy and computation for running a sensing and location tracking application continuously in the background. With these limitations, engaging participants in masses can be very difficult.

In this work, we define a new approach for designing massive crowdsensing systems where we offload the burden of sensing from smartphones to Bluetooth Low Energy (BLE) [1] proximity tags. We utilize simple advertisement sending BLE tags to detect the presence, mobility patterns and crowd behaviour. Contrary to the smartphone crowdsensing design, where all the participants are required to carry a smartphone, BLE proximity sensing requires a large population carrying relatively cheap off-the-shelf BLE proximity tags, and considerably fewer participants to run scanning application on their smartphones. This approach relieves the requirement of large smartphone user base for crowdsensing, and also relieves the participants from the burden of active sensing.

Our contribution is in the utilization of external smartphone-detectable proximity devices as crowdsensing alternative for mobility pattern analysis. Currently, BLE enabled tiny devices are available in the market to track personal belongings, find lost items and indoor localization etc. We explore the possibility of utilizing BLE proximity tags for crowdsensing experiments, which were not designed to be used in such dense deployments. We take advantage of the periodic beaconing of the BLE devices, which could be detected by nearby Master devices (smartphones) listening periodically for the advertisement messages. To our knowledge this is the first experiment, which utilizes these external smartphone-detectable proximity tags for crowdsensing and mobility pattern analysis.

Motivation

Since last year we have seen a revolution shaping up for BLE devices. Experts already foresee this new technology to become the corner stone for Internet of Things (IOT) [3] and serve as a better alternate for old generation technologies such as Radio Frequency Identification (RFID) and Near Field Communication (NFC). The BLE tags work by sending advertisement packets on 3 designated advertisement channels, to be discovered by a smartphone BLE scanner within advertised coverage range of 50-100 meters. The owner of the tag would "discover" and "connect" to it using a vendor specific application and establish an association between the uniquely identifiable tag and a physical item. This association is supported by a set of profiles that define uses for tags. In this whole procedure, the periodic advertisement beaconing mechanism is what intrigued us to utilize it for crowd presence and mobility detection without actually connecting to the tags.

We conducted a limited set of experiments for leveraging the power of BLE tag advertisements in a high-density setting. These experiments helped us to develop a BLE scanner application with parameters suitable for high detectability in presence of large number of BLE tags. During our lab tests, we were able to detect 200 unique tag advertisements easily in a 30 seconds scan cycle, where tags were transmitting advertisement beacons every 5 seconds. The longer scan duration helped to discover tags whose packets were lost due to collisions. The 30 seconds scan cycle was repeated every 5 minutes, considering the expected crowd mobility and sufficient logging for detection events. The crowdsensing experiment was performed mainly to understand the detectability ratio and the accuracy in detections by reconstructing the participant's routes.

Detectability & Route Reconstruction

Hajj [2] is a unique annual event that happens only in Makkah, Saudi Arabia. Two to Three Million Muslims from all over the world gather to perform a pilgrimage referred to as "Hajj". Hajj is a sequence of rituals performed within specific times and places. The Spatio-Temporal restrictions make the management of Hajj a very challenging task. It is only by understanding how pilgrims behave, their patterns, their interactions, their needs and demands, that we can reach to a satisfying level of providing services and experiences. Considering the importance and the unique nature of the Hajj event, we decided to gather data from a group of pilgrims and track their movement during the five important days of the event.

Experimental Setup
Based on the hypothesis that not everyone carries a smart-phone, and not everyone will be willing to use our application, our design allows the distribution of smartphone detectable BLE tags to be carried by pilgrims during their visit. BLE tag continuously advertises its presence by broadcasting its MAC address to nearby phones (approx. ~50 meters).

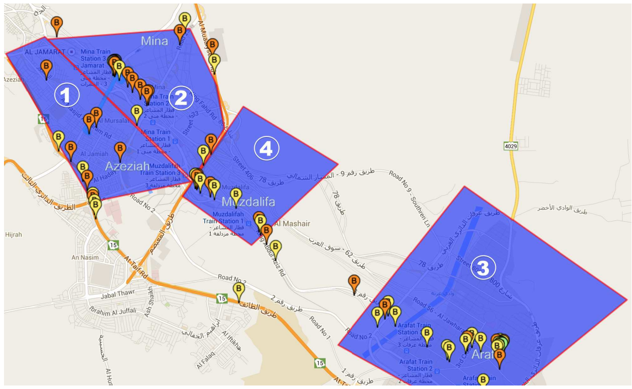

Figure 1: Region marking for pilgrims expected movement

Each smartphone was loaded with a BLE scanning and logging application, which transformed it into a data collection hub for advertisements received from any nearby BLE tag. Whenever a pilgrim carrying a tag passes by a smartphone running our application, his MAC address will be logged. To achieve this experimental setup, we collected a data sample by selecting four different groups from three different countries i.e. Pakistan, Brunei, Switzerland. We distributed around 600 BLE tags among the pilgrims in these groups and provided 10 Nexus 4 phones to the group leaders, pre-installed with our application, to act as a master device for BLE tags detection. The objective of the experiment was to prove our hypothesis, that advertising BLE tags can replace smartphone sensing for fine-grained trace collection.

Experiment Details
During the Hajj event, the pilgrims are expected to perform a defined set of activities in different regions. The

BLE Tags	Count
Distributed	600
Detected	542 (~90%)
Detected by 3+ master devices	398 (~66%)
Detected in defined regions	265 (~44%)

Table 1: BLE tag detectability

Routes	Count
(1 or 2) ->3 -> (1 or 2)	204
(1 or 2) ->3 -> 4 ->(1 or 2)	69

Table 2: BLE detections in defined routes (The numbers 1,2,3,4 refer to region numbers as mentioned in figure 1)

pilgrims visit different regions in a specified sequence and stay for a specific time period (unit of days). We have marked the expected regions with sequence numbers as shown in figure 1.

The collected data of pilgrim's movement is processed to produce visited region sequences in chronological order. Each pilgrim's region sequence trace is then matched with the expected region trace with the help of a finite state machine. The region trace matching helped us understand the movement of people and their behaviour during the event. We also developed a browser-based simulation application to demonstrate the movement of a specific pilgrim across different regions. A sample trace from the collected data is shown with the help of coloured markers in figure 1, where different colour of marker depicts detection by a unique master device.

Results

The analysis was performed in terms of BLE tags detectability and the successful route reconstructions. Table 1 shows that we were able to detect ~90% of the distributed tags. The ~66% detection of the tags by 3 or more master devices, proves our hypothesis that crowd mobility using BLE proximity tags could be detected by a fewer number of mobile master devices. We further analysed the data to extract detections in the expected regions. Collected traces were verified against two possible region sequences, containing mandatory regions during the Hajj event and in a specific sequence. Approximately 44% of the distributed tags were detected in the defined regions, while only a subset of them follow the expected region order as shown in Table 2. The tags which were not detected in expected region order were either 1) not in range of the master device 2) did not follow the right sequence while traversing through regions 3) were detected to be outside the marked regions due to GPS error on master device. We randomly decided the number of master devices for the experiment. Careful selection of number of master devices could help to improve the detectability rate even further.

Conclusion

Our experimental results prove that crowd mobility detection is possible by offloading sensing to the external smartphone-detectable BLE proximity devices. Further investigation in the data could reveal more interesting facts e.g. the route preferences, group/subgroup formation trends, travel time estimates, load conditions, inter-cultural behaviours, etc. With the increasing number of BLE enabled personalized devices, e.g. fitness tracking, health monitoring, item tracking etc., we hypothesize that it will provide more opportunities to gather fine grained data from the crowd which will open avenues for a variety of applications and research in crowd behaviour analysis.

Acknowledgements

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