Journal of Network and Computer Applications 98 (2017) 97–113

Contents lists available at ScienceDirect

Journal of Network and Computer Applications

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

SmartITS: Smartphone-based identification and tracking using seamless indoor-outdoor localization

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ARTICLE INFO

Keywords:
Localization
GPS-Wi-Fi-Cellular
BLE
GPS
IEEE 802.11
IoT
Wi-Fi
MAC
LBS
Bluetooth
Probe request

ABSTRACT

Localization in both indoor and outdoor environments is a long-studied problem. Using Smartphone for localization has also gained popularity recently. However, none of the existing solutions consider seamless localization and tracking of individuals in both indoor and outdoor stretches with significant accuracy. In this paper, we propose a human identification, monitoring, and location tracking system, called *SmartITS*, which continuously tracks MAC ids of user equipment (Smartphones, BLE tags, and Bluetooth devices) and can provide a Google map-based visualization of their trajectories. Our tracker is a portable mobile entity comprising of a Smartphone and an external Wi-Fi adapter which does not require any extra hardware infrastructure to deploy as well as does not need any modification in hardware design at all. Extensive testing with a prototype testbed system in densely populated areas shows that the *SmartITS* system can seamlessly track user trajectories in indoor and outdoor stretches with a high aggregate location accuracy which is up to 44.49% more accurate than the simple GPS based location tracking system. Our proof-of-concept prototype shows the usability of *SmartITS* architecture. We also perform several experiments for evaluating the Smartphone's performance as a scanner and as a sensor tag.

1. Introduction

In recent years, Smartphones are frequently used for several locations and mobility-aware applications for indoor and outdoor environments. In the race for rapid development of smart cities, Location Based Services (LBS) are used in various applications, such as human movement monitoring, traffic monitoring, crowd-sourcing, place finding, smart driving, and geo-tagging. LBS can play a significant role in making cities smarter by incorporating the knowledge of citizens' whereabouts, their visiting places, and trajectories.

In order to monitor and track the movement patterns of one or more persons in a densely populated area, the persons must be uniquely identified. Most of the mobile sensing applications are based on GPS, which is highly battery-consuming, and its positioning error can vary from 5 to 120 m (or more). However, the GPS accuracy also depends on the quality of Smartphone used. In addition, at many indoor locations, GPS does not work well (Maghdid et al., 2016). Also, many low-end cheap Smartphones have poor GPS accuracy which renders them unsuitable for similar applications. Wi-Fi based localization is an alternate technique for indoor localization which finds the location of a person carrying a Wi-Fi-enabled Smartphone with respect to fixed access points (Waqar et al., 2016). However, the use of Wi-Fi for outdoor positioning is not accurate in compared to GPS. Finally, the Cellular network based localization has an error of more than 300 m. However, accurate positioning can be achieved by using location-fingerprinting and time-difference-of-arrival (TDOA) based on Long-Term Evolution (LTE). The main issues are that these schemes require additional hardware infrastructure for deployment while, accuracy is limited in dense areas (Maghdid et al., 2016).

Existing localization systems (Ren et al., 2016; Im and De, 2016; Raychoudhury et al., 2015) based on the above localization techniques work for individuals and not for a large crowd as a whole. Moreover, they cannot accurately find the location of a person whose trajectory passes seamlessly through indoor and outdoor location trails. Human location tracking/monitoring can allow the authorities to search/identify a lost person among thousands in the crowd, to evacuate people during emergencies, to manage the crowd movements, and to predict the crowd in the future and to plan the resources accordingly. Researchers in (Al-Ali et al., 2008; Mitchell et al., 2013; Mantoro et al., 2011; Mohandes, 2011) have studied the similar type of systems. Al-Ali et al. (2008) proposes RFID-based localization system for Hajj pilgrims where the pilgrim locations are tracked using GPS-enabled RFID readers. Another such system (Mitchell et al., 2013; Mantoro et al., 2011; Mohandes, 2011) use RFID-chip augmented Smartphones to

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http://dx.doi.org/10.1016/j.jnca.2017.09.003
Received 2 September 2016; Received in revised form 9 June 2017; Accepted 8 September 2017
Available online 14 September 2017

upload user locations coordinates (along with their identification) to the remote server using available Internet connectivity. Some problems associated with these systems for large crowd localization and tracking are that they are expensive due to the requirement of the high number of RFID readers and infeasible to distribute to a large mass of people unaware of their usage. Moreover, the human body sometimes obstructs active RFID scanning. Also, localization using proprietary products (Libelium, 2016; Cisco Wireless Location Appliance, 2016) pose challenges regarding modification as well as integration with other systems.

In this paper, we take a step forward towards the identification, monitoring, and tracking of individuals in mass gathering using the probe requests emitted from user's wireless devices and a hybrid localization technique. This localization technique is based on the GPS-Wi-Fi-Cellular which tracks people, both in outdoor as well as the indoor environments in a seamless manner. In our proposed system, named *SmartITS*, we use a Smartphone as a sensing unit (called, Portable Sensing Unit (PSU)) which scans the frames transmitted by nearby wireless devices (Wi-Fi / Bluetooth (BT) / Bluetooth Low Energy (BLE) capable) passively and extracts their unique MAC ids in order to localize the carrying owners using the *PSU's* location coordinates. However, to the best of our knowledge, we propose a novel Smartphone-based human identification, monitoring, and location tracking system which does not require any extra hardware infrastructure to deploy as well as does not need any modification in hardware design at all. Moreover, in our system, *PSU*, a sensing unit is enough to capture probe requests and user's location without user's active cooperation.

In summary, the main contributions of this paper are as follows.

- We propose *SmartITS*, a novel identification, monitoring and location tracking system using a hybrid GPS-Wi-Fi-Cellular-based localization technique where the GPS-Wi-Fi-Cellular-enabled Smartphones scan and track wireless devices (Wi-Fi/Bluetooth/BLE) of mobile clients uniquely using their MAC ids. Smartphones used for sensing the users/clients do not need any modification in the hardware and do not require any Internet connection.
- We perform several experiments on Smartphones for evaluating their performance as a scanner and a sensor tag. Extensive simulation using a Wi-Fi frame injector shows that in indoor environment, each *PSU* handles high incoming frame rates (more than 5000 frames per second) and achieves high data upload rate via a lightweight and bandwidth adaptive technique. *SmartITS* also allows users to increase their Smartphones' detection probability (generation of probe requests) during the emergency.
- Real-time testing with a prototype testbed in a combined indoor-outdoor trajectory containing a large number of people and using Smartphones as *PSUs* have corroborated our simulation results and shows that *SmartITS* can achieve up to 44.49% higher localization accuracy w.r.to pure GPS-based system for indoor-outdoor environments.

The rest of this paper is organized as follows. In Section 2, we discuss the background of the wireless probe requests and its structure. Section 3 elaborates the related works. Section 4 gives the description of the system model and system architecture is discussed in Section 5. In Section 6, we describe the *SmartITS* system implementation and its operations. We have conducted several experiments for analyzing the *SmartITS* system performance in Section 7. Finally, we conclude the paper in Section 8 and provide directions for possible future extensions.

2. Background

A Smartphone with the increasing processing power can be used as a portable scanner for sensing nearby Wi-Fi devices. Wireless probes

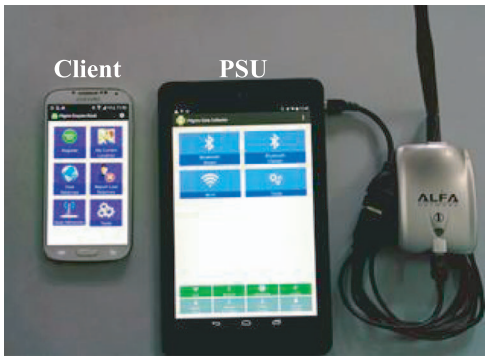

Fig. 1. Smartphone working as a Client (left) and *PSU* (right).

are 802.11 Management frames (IEEE 802 LAN/MAN Standards Committee, 1999) emitted by wireless devices in a pre-connection phase. When the Wi-Fi of Client's Smartphone is ON, it sends probe requests periodically to find an access point (AP) to get associated. Even if it is connected to an *AP*, it will try to find a better *AP*. These probe requests are intercepted passively by *SmartITS* (working in a monitor mode) using external Wi-Fi adapter. Fig. 1 shows a setup of *SmartITS* having a Client and a *PSU*.

The monitor mode allows a *PSU* to capture all the frames on the wireless medium; even the frames are not destined to it. The monitor mode does not require a device to be connected to a network. The promiscuous mode allows a *PSU* to capture only the frames belonging to the network it is connected. In the promiscuous mode, Wi-Fi frames are processed, and the IEEE 802.11 frame header is removed, while in the monitor mode all the frames are passed intact without removing any header. Therefore, it is better to use the Smartphone on monitor mode instead of promiscuous mode. A Smartphone transmits all kinds of frames, but probe request frames are of interest because they are transmitted on all channels and mostly when the Smartphone is not connected to an AP. The frame header contains important fields, such as *frame type*, *subtype*, *transmitter address*, *receiver address*, etc., where *transmitter address* is the MAC id of a user's Smartphone available near to the *PSU*'s scanning range.

In the rest paper, the terms *frame* and *probe request* are used interchangeably.

3. Related works

Nowadays, the usage of Smartphones is continuously increasing all over the globe. Recently, researchers have focused on developing Smartphone-based location-aware human identification, monitoring and tracking applications for both indoor and outdoor environments. The main requirements of a smart human location tracking/monitoring system for both indoor and outdoor environments are – high accuracy, low response time, low cost, high coverage and scalability (Maghdid et al., 2016). Recently, researchers have proposed the use of sensor-enabled Smartphones as a *tag* for large-scale human sensing/tracking which requires special software and hardware that must be incorporated together. Some of the Smartphone-based human/object location tracking systems, such as PDX Bus (Maghdid et al., 2016) requires an application to be installed on the Smartphone.

Many research works are focusing on single positioning/wireless technology, such as RFID (Ni et al., 2011), Wi-Fi enabled devices (Yang et al., 2015), BT/BLE tags (Deepesh et al., 2016), and Smartphone's GPS/General Packet Radio Service (GPRS) (Guido et al., 2013) to track human in indoor and outdoor environments.

RFID-based tracking and monitoring systems have significant performance issues, such as human body interference, expensive RFID readers, and low coverage area when deployed at the densely crowded places. Wi-Fi-based indoor localization, for instance, *fingerprinting* and *ranging*, both use Received Signal Strength Indicator