Computer Networks 88 (2015) 218–233

Contents lists available at ScienceDirect

Computer Networks

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

Survey of WiFi positioning using time-based techniques

Ahmed Makki*, Abubakr Siddig, Mohamed Saad, Chris Bleakley

School of Computer Science & Informatics (CSI), University College Dublin (UCD), Belfield, Dublin 4, Ireland

ARTICLE INFO

Article history:
Received 10 June 2014
Revised 23 June 2015
Accepted 28 June 2015
Available online 4 July 2015

Keywords:
Indoor localization
IEEE 802.11
Positioning
Ranging
Time of arrival
Wireless

ABSTRACT

Estimating the position of mobile devices with high accuracy in indoor environments is of interest across a wide range of applications. Many methods and technologies have been proposed to solve the problem but, to date, there is no “silver bullet”. This paper surveys research conducted on indoor positioning using time-based approaches in conjunction with the IEEE 802.11 wireless local area network standard (WiFi). Location solutions using this approach are particularly attractive due to the wide deployment of WiFi and because prior mapping is not needed. This paper provides an overview of the IEEE 802.11 standards and summarizes the key research challenges in 802.11 time-based positioning. The paper categorizes and describes the many proposals published to date, evaluating their implementation complexity and positioning accuracy. Finally, the paper summarizes the state-of-the-art and makes suggestions for future research directions.

1. Introduction

Rapid innovation in the area of wireless data communication has brought a wave of new applications to mobile phone and laptop users worldwide. The widespread deployment of wireless devices has attracted researchers to study the feasibility of utilizing embedded radio frequency (RF) transceivers to provide location based services (LBS) to users, as well as communication services. Positioning devices with high accuracy in indoor environments is of interest for a range of applications. Enhanced personal indoor navigation services are desirable in large facilities, such as airports, hospitals, factories and shopping malls [1], and are of particular importance to individuals with visual impairments [2]. Automated location tracking of personnel and goods has the potential to improve efficiency and response times in logistics [3]. Detection of occupancy patterns has proven effective in reducing building heating requirements [4]. On-the-spot advertising and coupon services have been proposed as methods for attracting and retaining customers. Accurate navigation for building evacuees, as well as tracking of fire fighters, is of great interest to emergency services [5]. In the security domain, location-based data access control, or geo-fencing, is seen as a way to enhance traditional password-based access control mechanisms [6].

The global positioning system (GPS) is widely used for outdoor localization. It provides good accuracy (2–3 m). However, it does not work well indoors due to attenuation of the RF signals from the GPS satellites by the building fabric. Many technologies have been applied to the problem of indoor location, including ultrasonic [7,8], InfraRed (IR) [9], ultra wide band (UWB, IEEE 802.15.4a) [10], WiFi (wireless local area network IEEE 802.11) [11] and Bluetooth [12]. Ultrasonic and IR approaches offer high accuracy at low cost but typically only provide proximity detection and require line of sight (LOS) between the transmitter and receiver. In comparison to WiFi, Bluetooth, which is currently being used for proximity beacons, lacks range (typically 5–10 m) and so requires a high density of newly deployed nodes. UWB, while offering very good ranging accuracy, has a low data rate and

* Corresponding author. Tel.: +353 1 716 2915; fax: +353 1 269 7262.
E-mail addresses: ahmed.makki@ucdconnect.ie (A. Makki), abubakr.siddig@ucdconnect.ie (A. Siddig), mohamed.saad@ucd.ie (M. Saad), chris.bleakley@ucd.ie (C. Bleakley).

http://dx.doi.org/10.1016/j.comnet.2015.06.015
1389-1286/

a very small installed base. WiFi positioning is particularly attractive due to the large number of WiFi-enabled devices already deployed. The ideal solution would be that the existing fixed WiFi infrastructure could be exploited for the purposes of accurate positioning with no hardware modification and without time-consuming manual RF mapping of the positioning space. This would open the way to near ubiquitous indoor positioning at very low cost.

Initial research on WiFi positioning, circa 2000, focused on received signal strength indicator (RSSI) ranging and fingerprinting [13]. This approach is easy to apply since standards compliant devices make the RSSI reading available at the application layer. However, RSSI ranging provides poor accuracy in buildings because RSSI is not well correlated with distance due to multipath. Fingerprinting methods seek to avoid this problem by using RSSI maps to record the variation of RSSI with position. RSSI maps are built by recording the RSSI observed from all in-range access points (APs) at reference points, typically on a 2 m grid, throughout the building. Mobile devices estimate their position by observing the RSSI readings for all in-range APs, i.e. their RSSI signature, and searching the map for the reference position with the best matching signature. The method is standards compliant and so can be used on existing devices but only provides an accuracy of around 3 m [13,14]. Map building is onerous in terms of effort and the stored maps degrade when people or large objects are moved [14]. For more details on fingerprinting methods, the reader is referred to surveys in [14–18]. To improve accuracy and avoid the need for construction and maintenance of RSSI maps, researchers have proposed the use of time-based methods.

Time-based approaches seek to determine the distance between nodes based on observing the time of arrival (TOA), and possibly the time of transmission (TOT), of an RF signals. While challenging due to the high speed of propagation of the signals, these approaches have the potential for high accuracy positioning without the need for mapping and could replace, or enhance, existing RSSI methods. Time-based methods have shown promise. Nevertheless, many open research challenges remain. While most existing research has used older WiFi standards, continuing advances in WiFi technology and standards are providing new opportunities to address these challenges.

This survey focuses on time-based approaches to the indoor WiFi location estimation problem. To the best of the authors' knowledge, this is the first survey paper addressing time-based WiFi positioning systems. Herein, we consider previous published proposals and make suggestions for potential future developments in the field. The aims of this paper are to provide a comprehensive retrospective of previous work together with a springboard for future work in this promising but challenging area.

In Section 2, we provide an overview of the 802.11 standard from the point of view of localization. Section 3 provides background on the principal time-based geometric location estimation algorithms. Section 4 examines the key research challenges in time-based WiFi location estimation. Section 5 surveys all previously proposed time-based WiFi location estimation techniques. Section 6 discusses our findings and makes suggestions for future work. Finally, Section 7 concludes the paper. A list of acronyms used in this paper is provided in Table 1 for the reader's reference.

2. IEEE 802.11 standard

2.1. Overview

IEEE standard 802.11 (also known as WiFi or WLAN) [19,20] is a wireless communications technology mainly used to deliver Internet Protocol communication services. This standard describes the PHYsical layer (PHY) and medium access control sub-layer (MAC) specification for wireless connectivity between fixed, portable and moving stations within a local area. Many amendments of IEEE 802.11 have been ratified, IEEE 802.11a/b/g/n/ac, and the under development IEEE 802.11ax, are concerned with enhancing communication speed. IEEE 802.11e/i/v/s/p amendments focus on quality of service, security, network management, mesh networking and vehicular environments, respectively.

IEEE 802.11 can also be employed to provide location estimation services. To date, researchers have focused on IEEE 802.11a/b/g. However other standards such as IEEE 802.11n/ac/v/ax, can play an important role in enhancing localization due to their extra features. The following subsections examine IEEE 802.11 from a localization point of view. A summary of the standards is provided in Table 2.

2.2. IEEE 802.11 channel access method

The IEEE 802.11 standard for WLAN defines a distributed coordination function (DCF) mechanism for accessing the medium based on a Carrier Sensing Multiple Access with Collision Avoidance (CSMA/CA) protocol. Optionally the standard defines a centralized MAC protocol, Point Coordination Function (PCF) [21], to support collision free and time bounded services. In this paper we limit our description to the main aspects of the DCF concept. For more information about the medium access mechanism, readers are directed to [21]. DCF uses mandatory periods of idle time on the transmission medium known as inter frame space (IFS) and allows for priority access to the wireless medium. The two most important IFS times are the short inter frame space (SIFS) (about 10 μs for 802.11b) and the DCF inter frame space (DIFS) (about 50 μs for 802.11b). DCF consists of a basic two way handshaking access mode as well as an optional request-to-send (RTS)/clear-to-send (CTS) four-way handshaking access mode [21].

In basic access mode, the node senses the channel to determine whether another node is transmitting before initiating a transmission. If the medium is idle for a DIFS time interval, the transmission will proceed. Otherwise if the medium is busy, the node defers its transmission until the end of the current transmission, and checks again if the medium is idle for a DIFS time interval. In the case of successful packet reception, a positive acknowledgement (ACK) is transmitted by the receiver node to the transmitter node after a SIFS time interval [21]. A SIFS time interval is used to give priority access to ACK packets [20], e.g. if two nodes try to access the medium at the same time, the one that has to wait for a SIFS time interval (10 μs for 802.11b), i.e. in the case of ACK, wins