3-D Localization of Indoor Access Points via Opportunistic Crowdsensing

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***Abstract*—I propose a new approach to estimate the 3-D location of indoor access points by combining various data points, such as outdoor Wi-Fi with GPS data and indoor Wi-Fi information, utilizing crowd-sensing to leverage the power of publicly contributed user information. The main contribution of this approach lies in eliminating worker tagging and any indoor information. Since all data collection and processing can be done in the background, it erases the administrative burden by augmenting the human experience.**

I. Introduction and Motivation

The usefulness of the Wi-Fi access point (AP) location information is increasing. One of the most typical usages is device localization. As a growing interest in indoor location-based services (LBS), several methods have been proposed to estimate the location of devices such as smartphones using the AP locations as anchors indoors where GPS is insufficient. The AP locations information also can help Wi-Fi clients such as smartphones perform more efficient AP selections and association control if they know the locations of surrounding APs. For example, if the client can acquire the 3-D locations of indoor APs in a building in advance, the client can allow connections only to those APs installed on the floor to provide stable communication to the user on the same floor. Furthermore, the AP locations are significant in building and site AP management. If the AP administrators can know real-time surrounding AP location information when the radio interference degrade a specific AP performance, they quickly understand which APs and in which channel frequency the interference is occurring. Then they can efficiently relocate the APs or change the APs' channel frequency. Besides, administrators can easily find unauthorized APs (i.e., rogue AP), including suspicious smart home devices such as hidden cameras that often function as Wi-Fi access point points. In these examples, it is desirable to obtain the locations of the APs inside the building in 3-D.

There have been proposed various methods to estimate AP locations, based on measurements of their beaconing. In particular, thanks to the penetrations of recent smartphones with the cost of communication, such measurement can be realized by the help of a crowd of people, and opportunistic and participatory sensing systems have been considered as fundamental infrastructure. However, most of the existing AP localization methods based on Received Signal Strength (RSS) of the beaconing measured assume that GPS, other positioning systems, or manual inputs of by the collaborators are available and the measurement positions are known, which significantly impair the scalability of the localization method and makes it challenging to apply to indoor APs.

In this paper, I leverage smartphones of crowds to build city-level, indoor/outdoor 3-D AP location database. My approach never forces collaborators to do massive sensing on their phones and to perform manual input and do not require any prior knowledge such as floor maps. I start with simple, passive opportunistic sensing of Wi-Fi beacons with GPS locations outside, to localize "virtual" APs. The virtual AP represents a virtual source of the signal on the building from the AP in the building to outside. This is estimated by my previous work in [1]. After those virtual APs are localized, we leverage Wi-Fi beacon sensing in indoor, *without GPS*. By estimating inter-AP relative distance and applying the 3D MDS technique, relative coordinates of APs in the building are determined. Finally, we use the virtual AP locations to map the relative locations onto physical location in the building.

II. Challenges

To estimate the location of indoor APs, the anchors, which are reference points for the localization, are necessary. For example, the location of the measurement point is the most commonly used anchor, and many methods use these locations to estimate the AP location based on triangulation and the estimation of the propagation parameter. The problem is how to obtain those locations since the positioning accuracy by GPS deteriorates indoors. Although dead-reckoning is one way for indoor device positioning, it has a severe problem that positioning errors accumulate, and power consumption of the device is high due to the excessive use of internal sensors in addition to Wi-Fi beacon scanning. Particularly significant battery consumption is likely to frustrate smartphone users, making it challenging to obtain a large number of collaborators needed for a wide range of data collection. Crowd-sensing collaborators' manual recording of the measurement positions is a more straightforward way to obtain indoor locations. However, it increases the burden on workers, and it also makes the design of the crowd-sensing system complicated since it is necessary to include mechanisms and interfaces that allow the workers to record indoor positions, which probably require

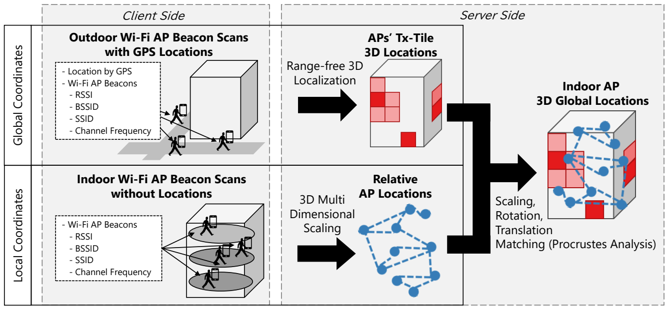

Fig. 1. Method Overview

floor maps. Depending on the building, infrastructure-based positioning such as RF-ID tags, acoustic devices, Bluetooth beacons, and Wi-Fi fingerprints localization may be available; however, it is limited in the available area, although everyone can install Wi-Fi APs anywhere.

There are a few methods that claim to be able to estimate the AP locations without pre-deployment or any calibrations. Those methods achieve high localization accuracy and save collaborators' labor, but they consider that some of the indoor device locations by GPS can be obtained and used as anchors [2], [3]. They assume relatively accurate GPS locations can be obtained near the entrance of a building or near the window, even indoors. In their experiments and evaluations, the grand-truth of measurement points are used instead of the location provided by indoor GPS. Hence, whether they are useful in the real environment is unknown.

As a preliminary survey, I investigated the indoor localization accuracy by GPS in an urban environment. Measurements are performed on multiple floors, and 67 measurement points are obtained in total. In 18 points of them, I could not get the location by GPS, and the average localization error of the remaining points is 44.7m, the maximum is 285.5m, and the minimum is 2.7m. Even when focusing on 39 measurement positions near the window and the entrance, the average error is 25.5m, maximum is 58.7m, and the minimum is 2.7m.

A more serious problem when using indoor GPS locations as anchors is that we have no way to prevent the inclusion of measurement points with large GPS errors. Android OS provides horizontal accuracy of GPS locations as an API. The accuracy is defined as 68% confidence, therefore, this API cannot be use for prevent the inclusion of poor locations by GPS. In the measurements in the campus building, one location by GPS result in a 47.9m error in spite of the accuracy API provides 6.0. Even the inclusion of a few poorly accurate anchors will significantly degrade the accuracy of the AP localization with the methods above. Existing unsupervised localization methods cannot detect if this problem is occurring.

III. Approach

Fig. 1 shows an overview of the proposed approach. The key idea of the approach is to combine indoor and outdoor Wi-Fi measurements, while most existing efforts treat them as separate. This approach is comprised of three components. The first one is to obtain the virtual APs as the localization anchors based on the outdoor RSS values received from the APs inside the building. The second one is to determine the relative coordinates of APs in the building by estimating inter-AP relative distance and applying the 3-D Multi-Dimensional Scaling (MDS) technique; The third one is to use the virtual AP location to map the relative locations onto a physical location on the building.

I implemented the basic part of the approach and evaluated the accuracy of AP location estimation in a seven-story office building in the center of the city. I compared with the existing method *Selendipity* [4] and the result shows the average of 3-D localization error is 47.8m by *Selendipity* and 15.6m by the proposed method. Serendipity leverages the measurement locations by opportunistic GPS indoors as anchors, whereas my method uses the virtual AP location based on the accurate GPS measurements outdoors as anchors, which lead to this difference in the localization performance.

IV. Conclusion and Future Work

I proposed a new approach for 3-D localization of indoor Wi-Fi APs. It does not require any active worker tasks and prior knowledge such as known AP locations and floor maps, which allows all processing to be performed in the background, making it extremely scalable. In the latest result of experiments under the same conditions, it shows about three times the accuracy of the existing method.

Future works include comparing the proposed approach with other localization schemes to clarify its usefulness and efficiency, estimating the energy consumption at user devices in the measurement phase and, providing a strong motivation and examples for the importance of accurate localization of indoor APs. Furthermore, the approach is not limited to Wi-Fi access points but can be applied to other wireless standards such as Zigbee and Bluetooth low energy (BLE) used in today's commercially available smart home devices. Therefore, I plan to extend the approach to construct a home device location database indoors, which reduces the burden of the device and home management.

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