An Indoor Positioning System based on a WiFi router and FM beacons

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Abstract — **Wi-Fi based solutions are often suggested for indoor positioning as a trade-off between the performance and the associated costs. Multiple access point coverage is expected in large areas, such as enterprises, while in smaller areas, such as private houses, a single access point is not sufficient to localize a mobile device. In this paper, we propose a solution based on using FM beacons signal to deal with environments covered with only a single Wi-Fi access point.**

Keywords— **FM localization, indoor positioning, signal fingerprinting.**

I. Introduction

THE location of a mobile user has become an important requirement for modern applications in the area of ubiquitous computing. The Global Positioning System (GPS) is still the leading technology for outdoor navigation, but the situation is not as clear-cut when it comes to indoor positioning. There are a number of proposed designs based on technologies such as ultrasound, Bluetooth, infrared, Wi-Fi, GSM networks or other types of radios [1]. The shortcomings of these systems are mostly related to laborious deployment, low accuracy or expensive/dedicated hardware. In practice, one typically has to make a trade-off between the accuracy performance and the deployment costs, such that the solution becomes cost effective.

The past decade witnessed a number of research initiatives that exploit IEEE 802.11 (Wi-Fi) networks for the purpose of positioning [2] [3] [12] [14]. The wireless positioning approaches generally rely on signal propagation modeling and signal fingerprinting. Signal modeling assumes the use of the Received Signal Strength Indication (RSSI), the Angle of Arrival (AOA) or the Time of Arrival (TOA) measurements to which the mathematical models are applied. This results in estimation of the location of the user [2]. Within the signal propagation models it becomes difficult to address all the characteristics of signal propagation, therefore the accuracy of propagation models is limited [3]. The signal fingerprinting approach is based on the fact that each point in a covered area has a unique fingerprint of signal parameters from nearby access points. Thus, the mobile user's position can be calculated by comparing parameters measured at an unknown location to the database that contains fingerprints and the corresponding real coordinates.

An indoor localization system based on Wi-Fi signal strength is an effective solution due to the fact that Wi-Fi networks are increasingly available in everyday life, while mobile units such as cellular phones, widely support them. However, the localization has shown good results in large areas covered with multiple Wi-Fi access points (such as airports, shopping malls, enterprises), while in smaller areas (such as private houses) these positioning systems face a difficulty using a single access point (for example, a personal Wi-Fi router). This is because one access point is not sufficient to localize a mobile device with an acceptable accuracy.

Acquiring and installing additional Wi-Fi stations may be an expensive solution; instead, we propose short-range FM emitters for a number of reasons: a) FM emitters in general are cheaper than Wi-Fi access points and are also widely available off-the-shelf; b) a PDA or a cellular phone with an embedded FM receiver can also be used as a client device, c) FM radio is much more power-effective, an average FM receiver consumes around 15mW compared to almost 300mW of Wi-Fi in receiving mode [4, 5], d) Wi-Fi is more prone to interference than FM since its signal belongs to a radio frequency range of 2.4/5GHz that is shared with other common electronic devices such as cordless phones [6] or microwave ovens [7], e) the propagation of FM radio signals is more stable and predictable in indoor environments in comparison to Wi-Fi because of smaller objects that interfere more with a Wi-Fi radio than that of FM waves, due to frequency bands that they use [8]. Furthermore, in our previous work [8] we have demonstrated that our FM positioning system performs comparably to and in some cases even better than Wi-Fi. Therefore, we propose the deployment of FM transmitters, in addition to the existing Wi-Fi router, in order to design a cost-effective solution for indoor positioning.

The rest of the paper is organized as follows. The next section provides a review of the current literature. In Section III we describe our method of combining one Wi-Fi station and two FM transmitters for localization. Then, in Section IV we provide the description of the experiments and the accuracy of the system with one Wi-Fi access point and initially one and subsequently two FM beacons. Finally, we draw the main conclusions.

II. Related Work

The use of IEEE 802.11 wireless infrastructure for

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localization has gained significant interest over the past decade, due to their wide deployment and good coverage in urban areas. One of the first projects that employed RSSI fingerprint technique was RADAR [2]. Both, propagation modeling and fingerprinting have been used and the authors reported 25th and 50th percentile errors of 1.92 m and 2.94 m respectively. In order to determine the mobile user's location, the k-nearest neighbors (kNN) algorithm was applied. Wassi et al [3] studied multilayer perceptron, generalized radial neural network and kNN algorithms applied to the signal strengths measurements recorded from three IEEE 802.11b access points in an indoor space. They reported 2.4 m median error in the experiments performed in the 75 m long corridor with a width of about 2.5 m to 4.5 m. Ferris at al [12] designed Wi-Fi localization system using Gaussian processes in conjunction with graph-based tracking. They modeled user's moving through the rooms on the same floor as well as more complicated patterns of moving such as going up and downstairs. When tested over the 3 km data in the three floors building with 54 rooms the average error was 2.12 meters.

In our previous work [8] we presented the results of FM positioning for indoor environments and addressed the problem of recalibration by introducing a novel concept of spontaneous recalibration. There are few other works dedicated to FM positioning. The first positioning system based on FM radio was presented by Krumm et al. [16]. It was an outdoors-only positioning system that employed a prototype wristwatch device featuring an FM receiver, to distinguish six districts of Seattle using the signals broadcast from public FM stations. They recognized the correct district in about 80% of cases. More advanced algorithms enabled the system to locate the user with 8 km median accuracy [17]. Recently, Fang et al. [18] presented a comparison of FM and GSM outdoor localization within 20 reference points on an area of about 1 km^2. With 6-channel fingerprints, GSM accuracy was better than that of FM. However, by employing more FM channels they were able to improve FM performance significantly. It can be seen, that the previous works focus on outdoor localization using broadcast FM signals and special receivers (prototype wristwatch or professional spectrum analyzer). This paper, on the other hand, has a focus on employing FM radio for indoor positioning in the environments with only a single Wi-Fi access point which is a common case in private houses or smaller companies.

III. Our Approach: Wi-Fi Router and FM Transmitters For Localization

Our system uses one Wi-Fi access point and a set of short-range FM transmitters as beacons (Fig.1). A programmable radio serves as a client device. Relative position of the user regarding beacons is usually characterized by signal propagation time, angle between directed antennas and received signal strength indication (RSSI). In the case of FM positioning we identified signal–to-noise ratio (SNR) and RSSI as possible measures of distance between transmitters and the user. Our experiments showed that SNR of an FM signal is almost a step function which is unsuitable for high-accuracy positioning. Therefore, we chose the RSSI as a parameter suitable for FM positioning also considering the fact that most of the current FM receivers provide it to enable auto-tuning.

Fig.1. Wi-Fi router and FM transmitter

In addition to measuring location fingerprints it is also important to distinguish different beacons that can be identified by their carrier frequencies or by the signal they transmit. In the case of FM, due to the so-called "capture effect" it becomes impossible to use the same frequency since the strongest signal always dominates while the weaker ones get attenuated [10]. Hence, the transmitters are tuned to different frequencies and the receiver switches between them. This, in turn, has an important advantage for larger-scale deployments with regard to reducing interference between beacons, since any distant beacon will not be considered due to the "capture effect". In our system, there is no need to distinguish between Wi-Fi stations since there is only one, while for estimating the distance we use also the RSSI that is typically reported by the Wi-Fi enabled client devices. However, if there are two or more available Wi-Fi access points, they can be easily distinguished by their MAC addresses.

The first step in the deployment of the fingerprinting technique is performing a site-survey of RSSI from Wi-Fi station and FM transmitters, which means collecting the location fingerprints; that is, vectors of RSSI values into a database. Then, the position of a mobile device is calculated by comparing the observed measurements with the fingerprint database and the best match is returned as the estimated location. The matching is usually performed by applying machine learning techniques and in the current literature there is no general consensus regarding which technique provides the best performance results. For the system described in this paper, we chose Gaussian Processes (GP) regression. Ferris et al. [12] emphasize GP regression for the localization based on RSSI from the following reasons: a) GP does not require a discrete representation of an environment, b) as a non-parametric approach it is suitable for approximation of a very wide range of non-linear functions, c) GP provides uncertainty estimates for predictions at any set of locations and d) GP parameters can be learned from training data via well-known algorithms. In the next section we provide the description of the experiments and the results that reflect the performance of our positioning system using Gaussian Processes regression.

IV. EXPERIMENTAL RESULTS

Our approach is evaluated in Ubiquitous Interaction lab (Fig. 2) of CREATE-NET [11].The lab dimensions are 12x6 m and the room contains office furnishing. The receiving device used in the experiments was an HTC Artemis smartphone with built-in FM received and Wi-Fi module. A custom, low-level library written in C++ was used to control the FM tuner while Wi-Fi signal strengths were provided by OpenNetCF SDF library [12]. Acting as an FM antenna, a standard HTC headset is used. The smartphone used in our experiments provides FM signal strength in 45 levels while Wi-Fi RSSI is reported in 6 different levels due to the firmware design. In addition to a single Wi-Fi we placed two FM beacons in the corners of our lab. Depending on the size of the testbed more FM transmitters can be added while the rest of the approach remains the same.

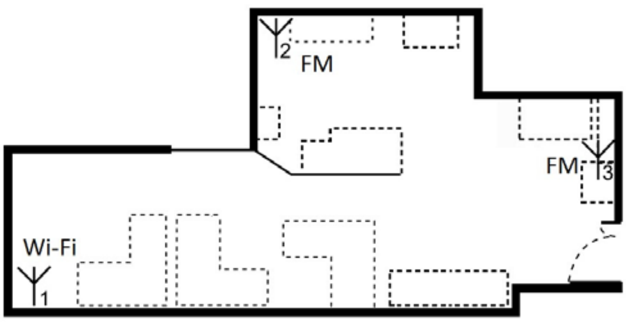

Fig. 2. The layout of the lab, positions of transmitters and the room furniture.

The RSSI for both Wi-Fi an FM signals was measured in each point in the lab following a grid of 0.5m.

Not all points were accessible so the data set contains 140 points with 20 samples per point. It should be mentioned that initially there were 100 samples for each point in the set, but the results did not show any notable degradation after the number of samples was decreased to 20. Hence, both FM and Wi-Fi show a relatively stable performance and 20 signal samples sufficed without the degradation in the system's accuracy.

The positioning accuracy is estimated by applying the leave-one-out method, selecting one point from the dataset as a test one while excluding the rest of the samples that correspond to this point. The procedure is repeated for the whole set and the errors are calculated as a Euclidean distance between the ground truth and the location estimation. Fig.3. shows cumulative distribution function (CDF) of the error in case of adding one, two or no FM transmitters to Wi-Fi access point.

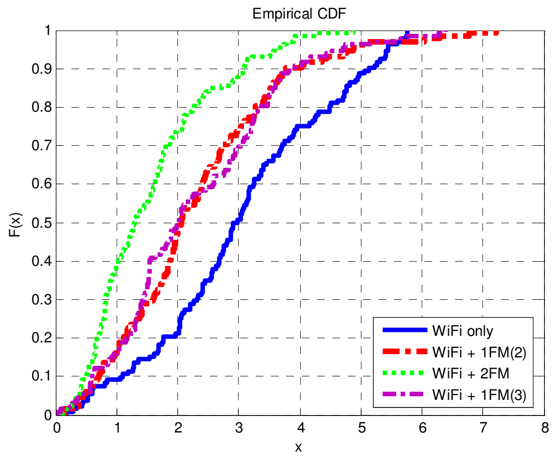

Fig. 3. System's performance when 0/ 1/ 2 FM beacons are added to Wi-Fi access point

The median estimation error (50^{th} percentile) of the system is 2.92m when only RSSI from Wi-Fi is used for positioning. Adding one FM transmitter improved the median error to 2.1m (adding the transmitter No.2, Fig. 2) or 2m (adding the transmitter No.3, Fig. 2). Lastly, adding both FM beacons resulted in the improvement of 50^{th} percentile error to 1.27m.

It is difficult to fairly compare our results with the performance of other positioning systems considering that the positioning accuracy depends on the physical parameters such as layout of walls, furniture, beacon positions and the size of a test bed. However, as a reference overview Table 1 shows the accuracy of different indoor positioning system.

V. CONCLUSION

The paper presented an indoor positioning system based on the combination of FM and Wi-Fi radio technologies. The system is intended for the environments covered with a single Wi-Fi antenna such as private houses or small

TABLE 1. COMPARISON OF LOCALIZATION SYSTEMS

Project	RADAR [2]	Wassi et al [3]	Ferris et al [12]	Chan et al [14]	Our System
Error calculation method	CDF (50%)	CDF (50%)	Average error	Trajectory estimation error	CDF (50%)
Data Analysis Method	kNN	MLP, GRNN, kNN	GP	kNN	GP
Error in meters	2.94	2.4	2.12	1.1	1.27

offices. FM transmitters are widely available in electronic shops while any cellular phone or PDA with built-in FM tuner and Wi-Fi can be used as a client device. When tested in the space with the size of 50m² the median error was only 1.27m.

While outdoor positioning is a mature technology, the indoor localization is still relatively new and it is attracting increasing attention. This is mostly due to the fact that it opens up a door to a spectra of novel applications that span various domains, ranging from locating lost keys to recognizing moving patterns of elderly, used for detecting early symptoms of dementia [15].

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