

Performance Evaluation of a Self Calibrated 3D Wi-Fi Fingerprinting Positioning System

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Abstract—In this paper, we focus on building a monitored tool dedicated to the performance evaluation of indoor positioning systems. The idea is to develop an open software to measure Wi-Fi signal strengths and to add the positioning strategy directly inside the positioning server. This way, the comparison of various positioning strategies inside the same environment is easy to make. An other aspect is to make it possible to measure signals automatically in various locations. To do so, we developed an embedded controlled software inside a Wi-Fi-enabled drone to fly anywhere in the environment and to take many measurements.

The other key point in the paper is the description of a self-calibration function dedicated to fingerprinting methods. The objective is to make the fingerprinting method deployment fully automatic and to transform the initial manual calibration step into an automatic periodic calibration. This self-calibration function is an easy way to start the positioning function, sustainability and good accuracy keeping.

Index Terms—Indoor positioning, Fingerprinting location, Self-calibration, IEEE 802.11, Wi-Fi

I. INTRODUCTION

Indoor positioning is a hard task to achieve, because of multiple physical phenomena inside the building. All the techniques based on radio signals have a relatively bad accuracy because inside the building a lot of multi-paths occur and this causes the distances to be estimated incorrectly. In order to have good accuracy inside the building one must use line-of-sight methods such as lights, laser lights, ultra-sounds, radio signals... If there is at least one wall between the sender and the receiver, it is required to use a support that is able to go through walls, such as radio signals. Much work has been conducted in the last few years to define the right positioning function, which delivers an accurate computed position using measurements including multi-paths.

Three main techniques are used to build an indoor positioning function using radio signals:

- propagation models, sometimes adapted for indoor environments [1];
- fingerprint of the area and use of a comparison tool to define similar reception levels [2];
- geometric models using a description of the building structures.

The propagation models are very fast to deploy but the position accuracy is weak. The fingerprinting method is quite slow to deploy, because you need to fingerprint the area as the initial step of your positioning function; but the position accuracy ranges between 1 and 10 meters depending on the building complexity. The geometric model is very slow to

deploy, because you need to define all the elements inside the building very accurately. Accuracy is quite good inside the building but the calculation function takes some times to run.

We chose to work mainly with fingerprinting methods, which give quite good results. Furthermore, the fingerprint step seems to be the easiest task to automate in an extension called self-calibration. In order to self-calibrate the system, each Wi-Fi AP has to receive signals from all the others APs.

II. OPEN INDOOR FINGERPRINTING POSITIONING SYSTEM

Over the past decade, indoor positioning systems have become more common. First devolved to propose a less expensive positioning service, where the GNSSs (Global Navigation Satellite Systems) are inefficient or require an additional and expensive signal propagation-based infrastructure, they offer an accurate positioning of about 4m in rather homogeneous buildings¹.

In this original context, we first prefer fingerprinting location techniques that measure either the signal strength (RSSI) or the signal time of delivery (ToA – Time of Arrival, or TDoA – Time Difference Of Arrival). However, the weak point of this approach is the cost of the repository construction. And from simplified propagation models to more complicated ones (Friis, Friis calibrated, COST 231, Motley-Keenan [4], ray-tracing...), scientific and industrial communities have studied historization (Viterbi, Viterbi-like...), predictive models for mobility, without being able to exceed till the precision level.

What are then the main obstacles to the improvement and democratization of Wi-Fi-based positioning systems? We list five of them and choose to tackle them:

- automation of the calibration phase;
- taking into account the dynamic variations of the signal;
- combined use of other stand-alone or hybrid² positioning systems available;
- combined use of a 3D territory and collision-free travel modelling, and of real-time video streaming to refine the positioning on the basis of image analysis with or without markers, correspondence of views between actual

¹As opposed to a homogeneous building, a heterogeneous building refers to a territory where it is necessary to handle specific propagation models [3] designed to consider the physical characteristics of a building and other aspects: lift fields, multi-paths, absorption, reflection, etc.

²A hybrid positioning system allows to extend the positioning service over territories where only three GNSS satellites are visible, or when only one to three Wi-Fi access points (APs) have an audible and usable radio signal.

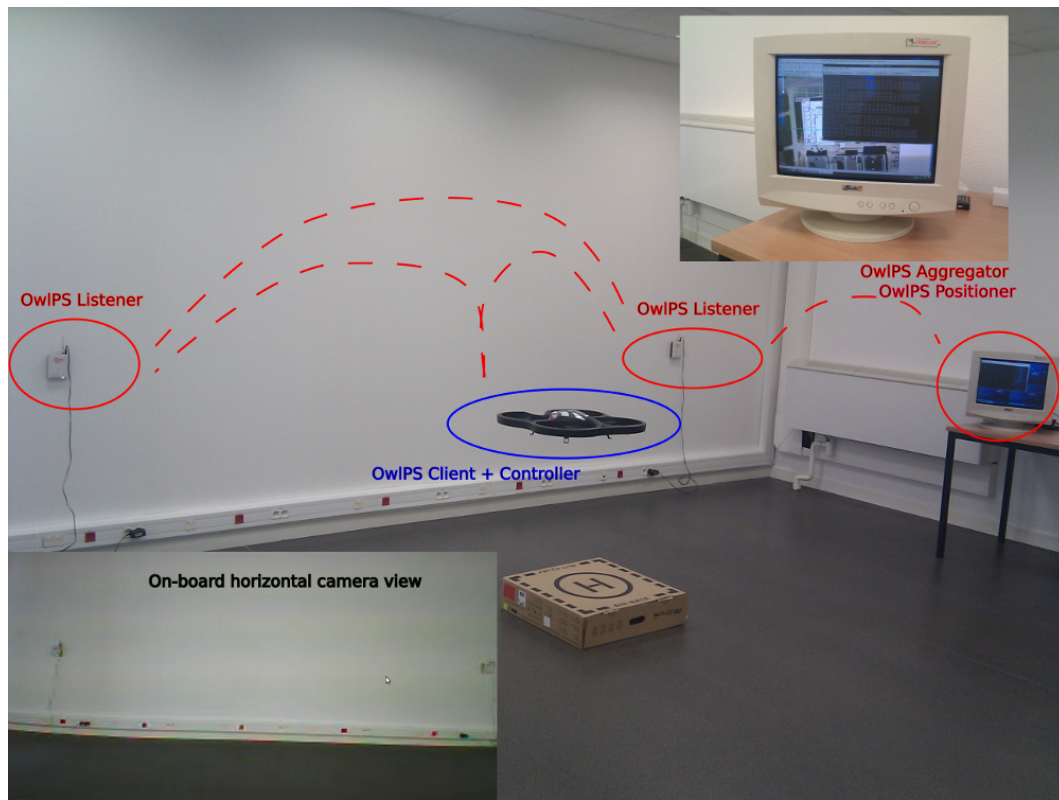


Fig. 1. OwlIPS platform and flying drone

and virtual ones, availability of compass and attitude of mobile terminals (MTs)...

- decision support to select and adjust the positioning device to the constraints of the area served and the quality of service covered.

In this section, and as part of our study, we will identify the first two points. We begin by introducing and describing the new features of the Open Wireless Positioning System (OwlIPS) briefly.

A. Basic OwlIPS platform

At the margin of commercial positioning systems (Eka-hau [5], Polstar...), OwlIPS [6] is a Wi-Fi-based positioning system, open source software produced by University of Franche-Comte, under a free software license, which implements the main algorithms and techniques used.

The main setup steps include the developments of:

- 1) a description of the building or, more generally, the studied area;
- 2) a description of the infrastructure (see Fig. 1) for transmitting and receiving the Wi-Fi signal: antenna gain, transmitted power, 3D positioning;
- 3) optionally, a description of the topology, or travel plan within the studied area;
- 4) the configuration of an explicit positioning, an implicit one, or both: that is, a position calculated by a process employing first an explicit request by positioning a

mobile terminal (OwlIPS Client), then a signal interception or an explicit request message positioning of APs liabilities. Each of these APs (OwlIPS Listener) then transmits information to an aggregation server (OwlIPS Aggregator). This aggregation server then requests a positioning server (OwlIPS Positioner), which in turn informs a monitor tool, or responds to the terminal.

- 5) setting of the duration and the frequency of the RSSI measurements;
- 6) mapping signal power received at different points of a territory;
- 7) selection of the positioning techniques to activate and compare;
- 8) design and implementation of new technology or new positioning algorithm.

Today that system proposes self-calibration and a mechanism allowing to calculate the on-demand or implicit position of a mobile terminal, that can take into account the dynamic variations of the received power, either of APs from APs, or of MTs to APs.

B. Self-calibration extension for fingerprinting

It is quite recently that the fingerprinting location automation has been considered as a key step. Originally, [7] proposes a virtual calibration method of the propagation model that does not require human intervention. On the occasion of the first edition of IPIN [8], many additions were made to the

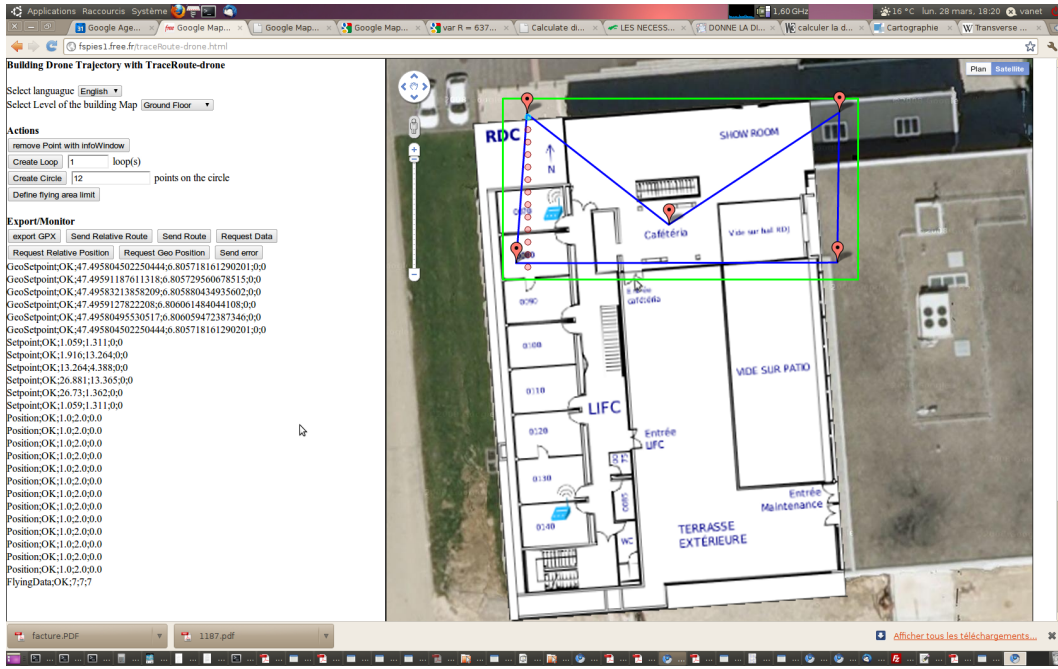


Fig. 2. OwlIPS monitoring tool

development of this feature. Latest version of OwlIPS allows to deploy and activate various APs (Linksys, Foner, mini-PC, EeePC). Self-calibration is activated and each AP then sends an explicit positioning request which will be intercepted by the deployed APs able to hear it. Each of these APs then analyzes the signal power associated with this message and forwards it to the aggregation server, which transmits the aggregated request to the positioning server. The positioning server then computes the matrix of the received signal strength by any AP_i from any AP_j , with $i \neq j$ for a given reference time t_0 . This matrix can, upon request, be enriched with information concerning one or more propagation models considered. In the case of FBCM [9], the knowledge of the AP coordinates, their antenna gain and transmitted signal strength powers, in a described building are used to calibrate the Friis propagation model.

It is also possible to determine the expected RSSI measurements virtually on a dense grid of reference points (RPs): RPs supplement the RPs associated to APs positioning description.

The, which assessments can be conducted and should they be?

First, there is the time economy issued from the self-calibration phase and nevertheless, the time required to perform this self-calibration phase. Then, this self-calibration phase may introduce a bias in the measurement of the Wi-Fi signal because many simultaneous signals may produce interference (when the RSSI measurements are spread over the time of a semi-automatic calibration phase). This self-calibration phase may also facilitate and reduce the impact of the human shadow of the manipulator who is no longer necessary to calibrate the territory and to reduce the disruptive drag of Wi-

Fi signals.

In addition, assessing the impact of the density of the deployed APs is necessary. Passive APs (i.e. machines that listen for Wi-Fi signal without emitting anything, communicating with the infrastructure through the wired network) certainly introduce less interference than APs using ad-hoc mode. Such interference would be more identifiable when assessing the position of a mobile terminal or when tracking it. Such assessments would better set up the infrastructure elements (at least their location) to obtain a better positioning service. Moreover, the evaluation of the ratio between the number of APs on the error of positioning means would minimize the cost of the infrastructure when maximizing the targeted objective of positioning service quality.

C. A dynamic mechanism for an RSSI-aware positioning algorithm

The OwlIPS v1.2 system can configure the refresh rate of the RSSI fingerprinting matrix. In the context of an explicit positioning request by a mobile terminal, the positioning server can trivially apply the RADAR methodology [2] which performs a matching RSSI power, even as supplemented by a multilateration technique to refine the positioning of points located at reference point interstices.

Now the system is enriched by taking into account the updated matrix of RSSI self-fingerprinted power. This matrix is timestamped as M_{t_j} . It is matched with the nearest t_i positioning request.

What are the over-values of an up-to-date RSSI self-fingerprint matrix, when considering a homogeneous environment (room or outside) or a heterogeneous one and when

considering the conditions that make the Wi-Fi RSSI vary, such as door or window opening, human presence, new obstacles? Does positioning accuracy benefit from an updated calibration matrix?

Is it possible, at a time t_i to appreciate a human presence (MT orientation and relative positioning of the user) from a smart analysis, comparing M_{t_i} with $M_{t_{i-1}}$ and identifying the altered line-of-sight between APs?

III. PERFORMANCE EVALUATION OF THE POSITIONING RESULTS

The performance evaluation of positioning systems consists in measuring three parameters which are: integrity, accuracy and precision. Integrity means that the delivered coordinates correspond to where you are. Precision means that the standard deviation is near to zero. Accuracy means that the coordinates are near the real point. In order to evaluate the coordinates calculated by our system, we want to define a methodology to measure errors precisely, not only on one or a few points, but on many points in an automatic way.

A. Methodology and comparison functions

The selected method consists in using an indoor-flying drone with a Wi-Fi interface which will send and receive Wi-Fi packets. We want to have the ability to establish both the real coordinates and the calculated ones. The real coordinates will be measured thanks to on-floor markers captured by the vertical camera and the computed coordinates are defined by the positioning server.

It is necessary to run the same experiments several times to make statistics of the values, to have good confidence in the results. The reproducibility of the experiments is essential for that and we developed a tool to monitor the experiment (see snapshot in Fig. 2). In this monitor tool, we can define the roadmap and we can measure the differences with the calculated points which are represented graphically on our tool. In fact, we use the HTTP client function inside the Javascript to communicate with the on-board software localized inside the drone. The green rectangle allows to establish a correspondence between absolute coordinates (latitude and longitude coordinates) and relative coordinates in meters.

We want to study four aspects of positioning systems which are:

- two types of indoor environments, a room and a building;
- various Wi-Fi AP densities in an area;
- two types of calibration step which concern fingerprinting, manual calibration and self calibration;
- various numbers of Wi-Fi terminals inside the platform.

B. Experiment Description for automatic measurements

The first part of the experiment is conducted in a big room ($10.50m \times 6.5m$) with four Wi-Fi APs (Fonera 2.0 with OpenWRT Kamikaze which is an embedded Linux distribution) localized near each corner of the room. The APs include an Atheros chipset driven by the *madwifi* tool, *libpcap* and *Radiotap* headers. Part of our OwlPS software is on-board

and realizes Wi-Fi measurements for each selected packet. The aggregation server and positioning server are both located on a Debian GNU/Linux EeePC. Finally the located device is a Parrot AR.Drone which is a quadricopter running an embedded Linux kernel. This drone integrates horizontal and vertical cameras with a Wi-Fi device (Atheros chipset). A reproducible track roadmap is sent to our software running inside the drone in order to make a controlled move. Thanks to our software, many locations can be tested and evaluated automatically at various times.

The second part of the experiment is conducted in a building ($32m \times 41m$) over two floors with six Wi-Fi APs. It is interesting to evaluate the accuracy obtained with the automatic calibration compared to the accuracy with manual calibration only.

IV. CONCLUSION

Performance evaluation of local positioning systems is quite hard to realize. It is always difficult to compare results from two different papers. The need to develop an open platform which can switch from one method to another allows to make fair comparisons in a similar environment. Moreover, the time spent in measurements is decreasing thanks to the use of an automatically controlled drone which can make many measurements in various locations. This is very important, because past experiments often suffer from too few measurements to build statistics.

Our software OwlPS manages these two points which is a step forward for a monitored tool dedicated to indoor positioning system performance evaluation.

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