Evaluating indoor localization using WiFi for patient tracking

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***Abstract*—Our paper presents the first phase in developing an indoor localization technique based on WiFi for patient monitoring scenarios in patient empowerment and ambient assisted living settings. We describe an experiment that measures the accuracy for positioning using WiFi signals and the results show that decent accuracy can be obtained using existing equipment and with a minimum setting effort.**

***Index Terms*— ambient assisted living, indoor localization, sensors, tracking, wireless,**

I. INTRODUCTION

IN the context of increasing life expectancy in developed countries, increasing costs and prevalence of chronic diseases, new healthcare paradigms are proposed for decreasing the burden on traditional health systems. Patient empowerment [1], ambient assisted living [2], health oriented social networks [3] aim at providing adequate healthcare for home-based patients. In many of these scenarios, patient tracking is needed, however indoor localization is more difficult than outdoor localization, and the costs for deploying purpose-build sensor networks is prohibitive for the average user.

In our paper we develop and test an indoor localization technique using WiFi signal which has the advantage of using already available equipment as well as minimizing the effort for deployment. In section 2 we present a state of the art of existing indoor localization technologies, in section 3 we describe our experimental system, in section 4 we discuss the results and in the last sections we draw the conclusions and propose future improvements.

II. INDOOR LOCALIZATION USING WIRELESS TECHNOLOGY

Location tracking techniques can be classified into two categories: active systems that require devices to be worn by the person and passive ones, which comprise only devices embedded in the environment [4]. Given the complex calibration and large number of nodes required by passive techniques, current approaches favour the active system approach. Active systems are based on either triangulation (angle calculation between node and anchor points) or trilateration (distance measurement). Given the increased complexity and price for indoor triangulation hardware [5], most techniques employ trilateration via received strength signal index (RSSI) [6], time of arrival (ToA) [7] or time difference of arrival, which can achieve precision of up to a few centimetres [8][9].

An approach that is feasible for a limited number of enclosures based on RSSI involves "fingerprinting" a room. This involves recording the signal strength in multiple locations within the room beforehand. The user's location is established by mapping the signal strength to the pre-recorded map. Detailed in [10], the system uses a number of commercially available wireless routers, but experimentation is required to determine a minimally viable configuration, depending on the desired accuracy.

The same fingerprinting technique, but using Bluetooth technology is detailed in [11] The approach is evaluated using a large building and commercially available Bluetooth-enabled equipment. The experiment revealed that accuracy of up to 1.5m is possible using this technique when applied in a real-world setting.

The latest implementation of the technology, Bluetooth Smart promises much improved energy efficiency and a new software stack. Its usefulness for indoor localization was examined in [12], using two scenarios: a small scenario in an office environment measuring 8x11m, and a larger scale scenario, taking place in the entire wing of an office building, a triangular structure measuring 20.5x16x25.5m [12]. Several algorithms were considered, including trilateration as well as fingerprinting. Experimental results show that no algorithm provides consistent accuracy in both the small as well as large scale scenarios. In the small-scale scenario, both trilateration and fingerprinting lead to an accuracy within 3m, while in the large-scale experiment, only fingerprinting yielded the same result [12]. The main drawback presented within [11][12] is that RSSI is not well correlated with distance in Bluetooth, which seriously affects measurement accuracy. In addition, the fingerprinting method also encounters scalability issues when building the radio map for a large-scale location [12].

A more complex solution is detailed in [8], where authors

The work for this article has been part of the project EUROSTARS 9770 i-Light - A pervasive home monitoring system based on intelligent luminaires.

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978-1-4673-9575-5/16/$31.00 ©2016 IEEE

propose a time difference of arrival (TDoA) - a method based on the speed difference between electromagnetic and ultrasonic waves. The wearables are integrated into one of the user's shoes, as well as their hat, which receive and record electromagnetic pulses from three beacons installed within the enclosure. Tests comparing the accuracy of the system were undertaken within a 7x8m room in which the test system, using 3 telemetry beacons had a 30 square meters coverage. Static tests, in which the telemeter was not worn resulted in localization with a global average position error of 10.8cm, a figure that was replicated within dynamic tests, where the user followed a preset paths wearing the telemeter [8]. The experimental finding includes the importance of the telemeter's position within the user's garment, as well as possible error sources that can affect localization precision, such as temperature fluctuations that affect the speed of the ultrasound wave, obstacles (including the user's body) as well as ultrasound-opaque bodies that stop the emitted signal entirely.

The need for accurate, low-cost indoor positioning is also well within the attention of commercial players, where solutions based on several technologies exist. For instance, Zonith[1] provides a Bluetooth beacon-based system which allows locating and tracking any device, as long as it is Bluetooth discoverable. Similar systems, based on Bluetooth or WiFi beacons are provided by many companies, such as BlooLoc[2] , SenionLab[3] or Estimote[4].

Alternative implementations that do not employ radio-based networks include visible light communication. Recent research shows that LED and OLED-based lighting can achieve up to 10Mbit communication links using on-off keying that is invisible to the human eye [13]. The same technology can already be found adapted for indoor positioning by several commercial players, such as GE Electric[5] or Acuity Brands[6].

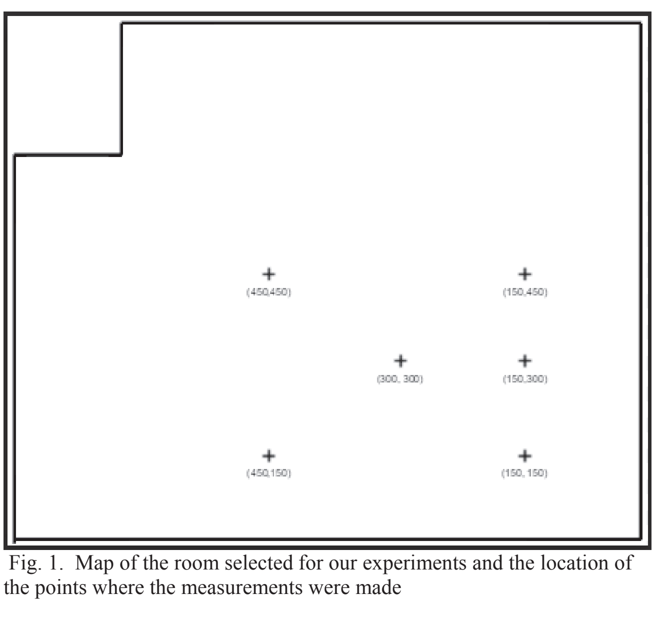

Fig. 1. Map of the room selected for our experiments and the location of the points where the measurements were made

III. Description of the System

A. *Short overview of the experiment*

The purpose of this experiment is to check if the data we can obtain is good enough to estimate the distance and positioning of a device with respect to multiple radio signals, by measuring the RSS power of the signal they are emitting, from multiple basic service set identifiers (BSSIDs). To do so, we take into consideration only the closest emitters, which as a consequence have the strongest RSS. Using their locations, we will further be able to estimate the position of the device using the measurements obtained from the receivers. For now, the article proposes to see whether the accuracy of the estimated values is good enough for an approximation to be made, by comparing them with the actual measured ones. Thus, it can be estimated, based on the measurements of the neighbors, how much the value at a certain point would be, and then compare that with the measurement.

B. *Implementation details*

To obtain the RSS of each BSSID, we used aircrack-ng's airmon-ng component on top of a Linux-based operating system, which captures the signals and prints the relevant information in a file. The command is:

```
>$ airodump-ng wlan0 -w test --write-interval 1 --output-format csv
```

In this command line we specify our interface, where to write the output and the interval at which the information should be printed into a file. Another script runs each second, 30 times such that it captures the information from the file built by the airodump command. This operation is repeated in each point, and afterwards we compute a mean such that we obtain a value as close as possible to the real one.

Based on the previously computed values, we estimate the power of each BSSID signal for the points that we want to check against the measured information. This is done by various mediation techniques (harmonic, geometric, median, arithmetic) that we apply on the data previously obtained. Afterwards, we compare the computed data with the actually obtained values, and compute any deviation errors, plotting the results in bar charts. For plotting we used the Phplot PHP library, which takes as input the arrays of values along with the corresponding labels, and produces charts formatted as specified.

C. *Computational experiment*

The location that we used to measure the information is indoor: we took into consideration a 40 square meter room, which has computers as well as tables and chairs dispersed

[1] http://zonith.com/products/ips/
[2] https://www.blooloc.com/
[3] https://senionlab.com/
[4] http://estimote.com/indoor/
[5] http://www.gelighting.com/LightingWeb/na/solutions/control-systems/indoor-positioning-system.jsp
[6] http://www.acuitybrands.com/solutions/services/bytelight-services-indoor-positioning

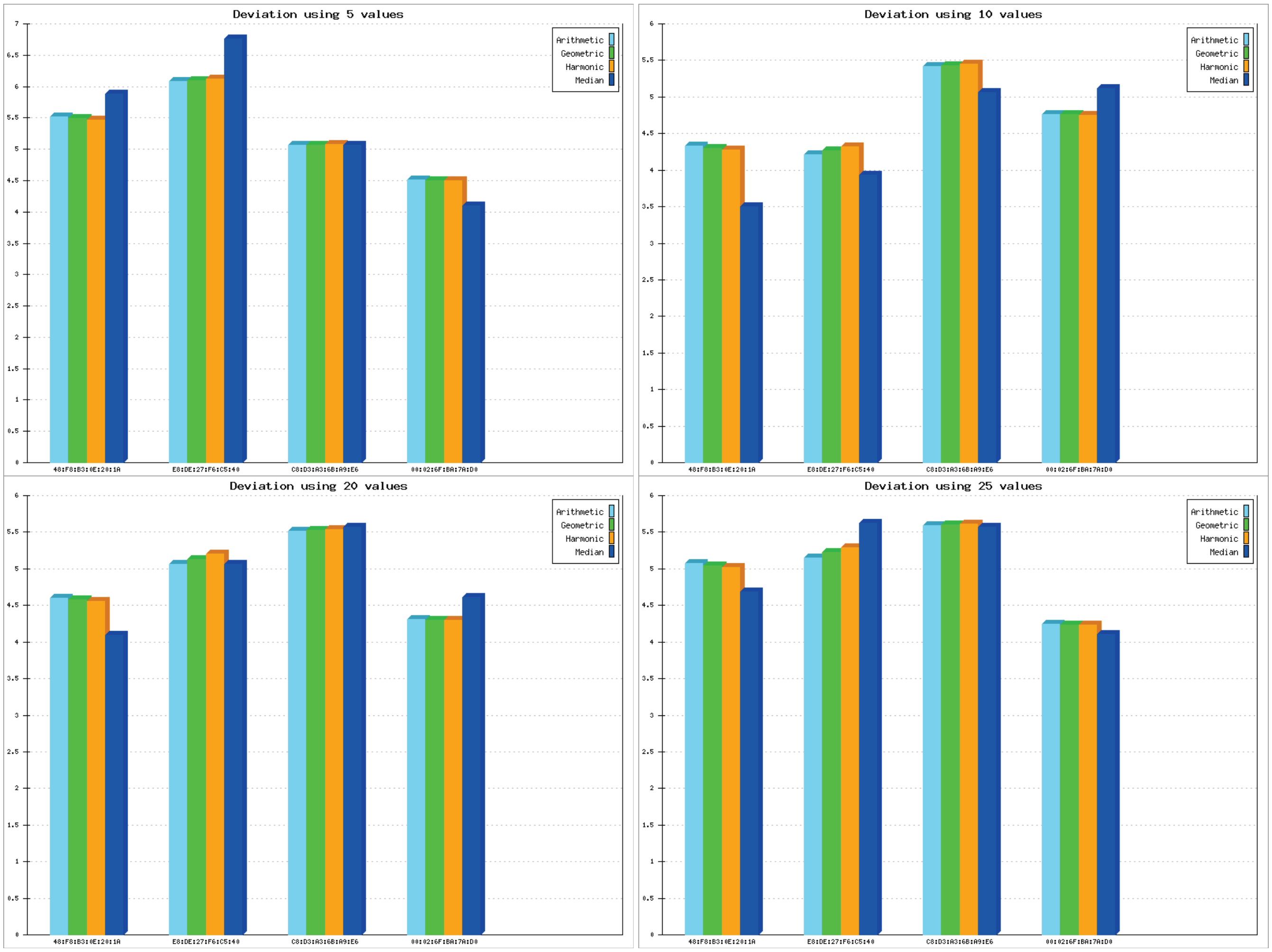

Fig. 2. The obtained standard error for localization using increasing numbers of measurements

symmetrically all around. Multiple signals come both from within the room, and from outside the room(such that there are interferences with walls). We chose points symmetrically disposed around the room, which we then measure by running the airodump-ng command for 30 seconds in each point, and save the information provided for all networks reachable from the given position every second.

Next, we processed the obtained information obtained in order to see whether the predictions match the reality: In the examples below we will present the data related to 4 points that we use as a reference and 1 other for which we compute an approximation of the strength of the signals it receives, then compare it with the actual measured one. We only take into consideration the 4 strongest RSS feeds, for more accurate results. Our application will compute, using an adapted MinSplStack, the closest points with respect to our given input point and then print out an approximation of the expected value based on the values of its 3 closest neighbors.

Finally, we compute the deviation error of the result as a percentage:

$$\frac{computedValue - \exp ectedValue}{\exp ectedValue} * 100$$

D. *Setting*

The chart in Fig 1 depicts the points within the room we used in the experiment. We measured using a 150 cm by 150 cm grid. As illustrated in the figure, we started measuring from the right-lower side. The points that are used as input data are (450, 450), (150, 450), (450, 150), (150, 150). The points for which we compare the inferred power with measured output and produce charts for in the paper are (300, 300) as shown in Fig 2.

There are about 14 WiFi signals which we were able to intercept consistently with our application, out of which we only take into consideration for this paper the most powerful ones with the MACs: 48:F8:B3:0E:20:1A, E8:DE:27:F6:C5:40, C8:D3:A3:6B:A8:A8, 00:02:6F:BA:7A:D0. Apart from the other WiFi emitters, there are also interferences generated by the furniture of the room.

IV. Results

When taking into consideration all the signals, the results for the error margin of the approximation show that the most accurate results are obtained for less values used for sampling, rather than for more. With regard with the most appropriate meaning type, the least error is obtained for the median one

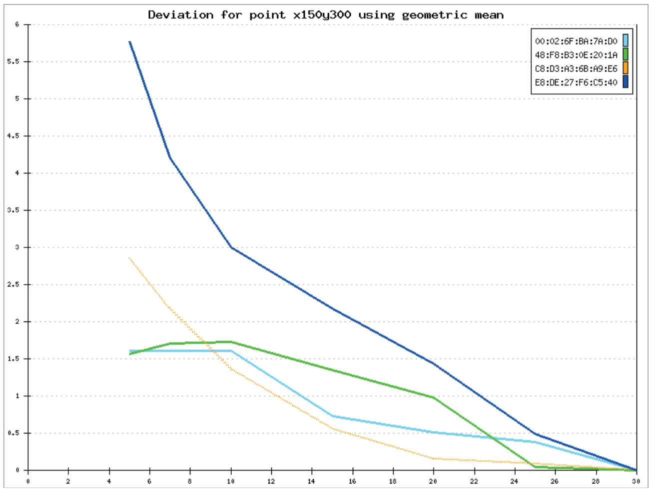

Fig. 3. Decreasing the standard error with more measurements

seems to be the most accurate. Among the 4 signals, there are two which appear to be best approximated, as 48:F8:B3:0E:20:1A and 00:02:6F:BA:7A:D0 have the least error deviation.

An atypical example is the 00:02:6F:BA:7A:D0 signal, if we take into consideration the Median mean, because is the most accurate one. While in the first case, taking 5 values for training, the deviation is 4.1021287572027%, it increases steadily if we take into consideration ranges of 7, 10, and 15 values. Afterwards, it decreases for a range of 20, and reaches the initial minimum for 25, of 4.1021287572027%.

In Fig 2, we present a comparison of the percentage of error that occurred for each measurement in the (300, 300) point. We used 4 meaning procedures, arithmetic, geometric, harmonic and median, in order the estimation of the point from the input provided by the closest 3 neighbors. Each graph describes the deviation obtained using a given number of values only (out of the total of 25 measured).

It should be observed that the best case is obtained when we only take 7 values, and then one WiFi signals will have a deviation under 4.7 percent. However, all cases present satisfactory deviation, due to the fact that it doesn't, in the worst case, pass 7% and most of the times it is under 5%. Generally speaking, the best procedure appears to be a traditional mean using the median technique.

Another purpose of the experiment was to find the minimum number of measurements for acceptable accuracy. In Fig 3 we show for a point how the standard error varies with the number of measurements.

We can deduce that for our approximation, the best options will be using the harmonic mediation, with a minimum of 15 samples, which would give us an acceptable error margin. In this case, for most of the mediation techniques, the deviation appears to be in an acceptable range.

V. CONCLUSION AND FUTURE IMPROVEMENTS

The article described the first phase in developing an indoor tracking system using wireless technologies. We presented an experiment using WiFi signals and have shown we can obtain decent accuracies using existing equipment and with a minimum setting effort.

As a future work, we intend to try different approaches to improve the correctness of the methods applied and results.

Our next approach will be to analyze the variation of the RSS power with the distance and estimate what the best cases and environments are. Our first experiment will consist in testing the maximum range of an transmitter up to -50 db(because after this barrier the data is less accurate), and analyze the variation of the power with respect to the distance, to further enable us to decide the best way to choose the most appropriate points as input rather than choosing the nearest ones.

Another important aspect is taking into consideration both the positioning of the signal sources and the degree of distance with respect to the target, due to the fact that the closest the source is, the more the accuracy of the signal increases, and thus, the position can be more precisely computed.

Furthermore, we should base the mediation on a logarithmic function rather than a mediation one, due to the fact that the power of an electromagnetic wave is not linear, but rather logarithmic - therefore the impact of a distance variation is not directly proportional with the source power.

As a final step, we should try to retrace our steps on a higher frequency electromagnetic signal and see if it has an impact on our results

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