# Comparison of localization methods using calibrated and simulated fingerprints for indoor systems based on Bluetooth and WLAN technologies

Eduardo Metola, Sofía Aparicio, Paula Tarrío, José R. Casar

ETSI Telecomunicación
Universidad Politécnica de Madrid
Madrid, Spain
{eduardo.metola, saparicio, paula, jramon}@grpss.ssr.upm.es

**Abstract** This paper compares two different localization algorithms to face the problem of indoor positioning using Bluetooth and WLAN technologies, which we have called: the fusion algorithm and the combination algorithm. The first algorithm is based on the construction of a fusion map using WiFi and Bluetooth power values. Considering the three lowest values of a defined distance, we compute the coordinates of the target point that we want to localize. In the second algorithm, the location determination is carried out independently with every single technology; then, results are combined to obtain a final estimated position. The performance of these methods has been tested experimentally using a simulated map and a real calibrated one. Using a real calibrated map, the localization errors obtained with the fusion algorithm are smaller than with the combination one, while when using a simulated map there is almost no difference between both algorithms. The results of the experiments made with the real calibrated map are a little better than using the simulated map, but the improvement obtained using the real map is not enough to confirm that using this one is worth, because of the effort necessary to build it.

**Keywords:** Context-awareness, Indoor Location, Fusion, WLAN, Bluetooth.

## 1 Introduction

Location is one of the emerging services related to mobile devices. Besides GPS, used in outdoors environments, there are several technologies, as WiFi, Bluetooth, RFID or Zigbee, some of them already embedded in most of mobile devices, which can be used in Location-based-systems (LBS). Because of their characteristics, they are frequently used for indoor communication. Then, we can take advantage of the already developed networks and use them to implement a localization system.

The aim of this paper is to compare two methods, based in fingerprinting, created to localize a target, using a real calibrated and a simulated map. In this work we have selected IEEE 802.11 wireless LAN (WiFi) and Bluetooth, as the technologies used to develop the localization system. Then, the maps previously mentioned are constructed based on WiFi and Bluetooth information. Some real experiments have been done to locate a real target object. Considering two different algorithms, we compare the obtained results using the simulated map with a real calibrated one.

This paper is organized as follows. Section 2 reviews some existing methods for location estimation using a single technology or by means of fusing data from multiple sources. In Section 3, we analyze the features of Bluetooth and WLAN in location systems. In Section 4, we introduce two localization algorithms: the fusion algorithm and the combination algorithm. The first algorithm uses a fusion map based on WiFi and Bluetooth power values. Considering the three lowest values of a defined distance, we have computed the coordinates of the target point to be localized. The second algorithm consists on the application of the first algorithm to two independent maps, one using only WiFi power values and another one using only Bluetooth power values. Then, the results are combined to obtain a final estimated point. Section 5 gathers some real experiments, using a real calibrated map and a simulated map. We compare the obtained results using the two algorithms and using the two different maps. Finally, Section 6 contains the conclusions and draws some guidelines for future research.

## 2 Background

There is a large amount of literature focused on indoor positioning systems using wireless technologies. Location in indoor environments is challenging because of the reflections, absorptions and multi-path phenomena suffered by the RF signals. Hence, LOS dependent parameters such as time of flight (time of arrival – TOA, time difference of arrival – TDOA) or angle (angle of arrival – AOA) based measurements used by other technologies are unsuitable. Moreover, most of these techniques need specialized hardware to extract the information [14]. Thus, most of techniques used in indoor localization are based on other features of the signal as the RSS.

Some of the wireless technologies used are RADAR, Infrared, RFID, etc. mentioned in [1], [2], [3], [4], [5] and [6], and other systems using Bluetooth are described in [7], [8] and [9].

The fusion of multiple technologies is an advantage since we can profit from the best features from each technology. For example, WLAN and sensors are used in [10] to improve location accuracy. A system based on RFID, WiFi and Vision is described in [11]. In [12] indoor location estimation based on Bluetooth and WLAN is presented. Most of the methods described above use RSSI and Link Quality information from Bluetooth devices.

Regarding the fusion methods, most works compute the location with every single technology independently. Then, the results are compared or combined to obtain a final estimated position. An interesting algorithm to solve this shortcoming is presented in [13]. As we will describe in Section 4, we introduce two different algorithms. The fusion algorithm is based on the construction of a map, using WiFi and Bluetooth power values. The combination algorithm consists on the computation of two independent maps using WiFi and Bluetooth power values respectively. Then, the results obtained with each technology are combined to obtain a final estimated point.

## 3 WLAN and Bluetooth in location systems

A well-known location technique used with 802.11x wireless LAN [1] and Bluetooth is based on fingerprinting. The basics of this method lie in the measurements of the power values from the Access Points (APs), WiFi and Bluetooth, and then, an estimated position is inferred by means of non-geometrical algorithms. The actual vector of power values measured in the client (as many values as APs displayed in the covered area) is compared with the vectors of values of each point of a fingerprinting map, previously measured or calculated and stored in a database. Finally, an estimated location is calculated applying different distance algorithms (Euclidean, k-nearest Neighbors, Minimax, etc.).

Specialized hardware is not needed to extract the power value; it can be directly read from the wireless card. However, this method has some limitations. For example, it is completely dependent on the target area that we want to cover. Any change in the distribution of the furniture, walls or even people walking along the area will substantially vary the power readings. Two kinds of problems are derived from these modifications. Firstly, sudden changes in the received power values when continuous location is being carried out cause large deviations of several meters of the target device's location estimation just in one second. Secondly, when variations in the environment are not occasional, former fingerprints in the database become obsolete causing steady errors in the location sensing. Systems that refresh the database are one of the solutions implemented to minimize the latter problem.

## 4 Localization algorithms

The proposed algorithms aim at determining the location of an object. They are based on the previous existence of a fingerprinting map using WiFi and Bluetooth technologies. Two distributions of access points are assumed: one consisting of Bluetooth stations and another one consisting of WiFi stations.

### 4.1 The fusion algorithm

This algorithm is based on the construction of a fusion map using WiFi RSS and Bluetooth RSSI values. We have used fingerprinting to measure the WiFi RSS and the Bluetooth RSSI received from each AP for each point of the map. Knowing the RSS received from every WiFi station and the RSSI received from every Bluetooth station, the location of the object can be computed.

We compare the RSS and the RSSI of the object, with the RSS and the RSSI of the points in the previous map. To do that, we use the minimax distance, i.e. the maximum absolute difference of the RSS or RSSI measurements. For example, let´s assume that we have three stations. Then we will have the RSS or RSSI vectors of the target object ($p_1$,$p_2$,$p_3$), and the RSS or RSSI vectors of a point in the fusion map ($p_{1,x,y}$,$p_{2,x,y}$,$p_{3,x,y}$). The minimax distance between these points is

$$d = \max\left(\left|p_1 - p_{1,x,y}\right|, \left|p_2 - p_{2,x,y}\right|, \left|p_3 - p_{3,x,y}\right|\right). \quad (1)$$

If we do not have any RSS or RSSI measure for an AP, a value of -92 dB is assigned, corresponding to the low limit of the RSS or RSSI.

Once we have defined a distance for each point, the position of the object is obtained using the same method as in [15]. This method consists of averaging the 3 nearest neighbors with some weights as follows. If $(x_{1,}\ y_1)$, $(x_{2,}\ y_2)$ and $(x_{3,}\ y_3)$ are the coordinates of these 3 points and $d_1$, $d_2$ and $d_3$ are the respective distances to the target object, the coordinates considered for this point are

$$\begin{aligned} x_p &= \frac{1}{2}\left(\frac{d_2+d_3}{d_1+d_2+d_3}x_1 + \frac{d_1+d_3}{d_1+d_2+d_3}x_2 + \frac{d_1+d_2}{d_1+d_2+d_3}x_3\right) \\ y_p &= \frac{1}{2}\left(\frac{d_2+d_3}{d_1+d_2+d_3}y_1 + \frac{d_1+d_3}{d_1+d_2+d_3}y_2 + \frac{d_1+d_2}{d_1+d_2+d_3}y_3\right). \end{aligned} \quad (2)$$

This method gives more weight to the points with a smaller distance.

### 4.2 The combination algorithm

This algorithm is based on the construction of two maps, one using only the WiFi RSS values and another one using only the Bluetooth RSSI values. For each map we follow the same method as before and we obtain two points, one for each technology. If $(x_{w,}\ y_w)$ and $(x_{b,}\ y_b)$ are the coordinates of these two points, we compute the final value with some weights as follows:

$$\begin{aligned} x_p &= \alpha_{wx} \cdot x_w + \alpha_{bx} \cdot x_b \\ y_p &= \alpha_{wy} \cdot y_w + \alpha_{by} \cdot y_b . \end{aligned}$$

(3)

It is known that the optimal values of these coefficients $(\alpha_{wx,}\ \alpha_{wy})$ and $(\alpha_{bx,}\ \alpha_{by})$ are inversely proportional to the quadratic error of $(x_{w,}\ y_{w})$ and $(x_{b,}\ y_{b})$ respectively.

## 5 Results

In this section, we present the localization results in a real layout, using a real calibrated map and a simulated map. These experiments have been tested using the two algorithms explained above.

The results presented in this paper are based on an actual WiFi and Bluetooth deployment at UPM Telecommunication Engineering School. The distribution of APs is shown in the map in Figure 2 for WiFi stations and in Figure 3 for Bluetooth stations. Black lines represent concrete walls and the green ones are glass and plastic walls.

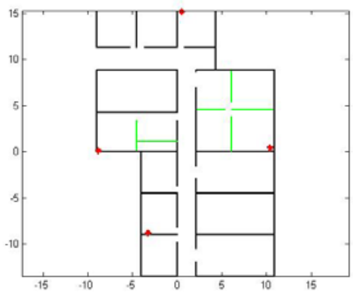


**Fig.** 2. WiFi access points distribution

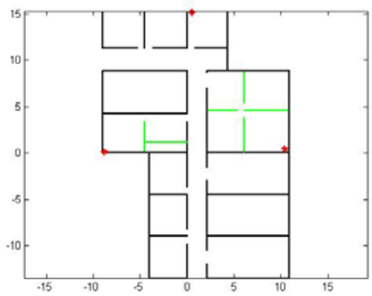


**Fig.** 3. Bluetooth access points distribution

We tested the localization algorithms using both technologies for several points in the map, Figure 4.

In the combination algorithm, we have considered the same weight value of ½ for WiFi and Bluetooth, because the computation of the optimal values is costly and an optimal choice of it does not improve significantly the results, given the conditions this experiment has been performed.

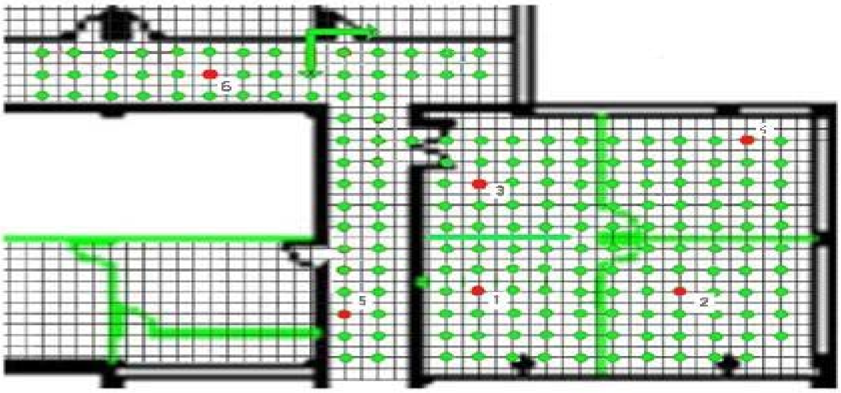

**Fig.** 4. Distribution of points where the algorithm has been tested.

### 5.1 Localization results using a real calibrated power map

In this case, the experiments have been done using a real calibrated map. To build this map we have measured the received power from every WiFi and Bluetooth station.

Knowing the RSS received from every WiFi station and the RSSI received from every Bluetooth station, the computation of the position of a real target object was made. We computed the WiFi RSS and the Bluetooth RSSI received from every WiFi and Bluetooth station respectively, for each real target object that we wanted to localize.

In Table 1 we summarize the average error and the estimation accuracy, obtained for the localization of several real target points using both algorithms and a real calibrated map. By average error we mean the average deviation for 100 measurements of each real target point. By estimation accuracy we mean the percentage of points obtained inside the room where the object is located. We have divided our map in different room areas, see Figure 5.

| Method | Point 1 | | Point 2 | | Point 3 | | Point 4 | | Point 5 | | Point 6 | | TOTAL | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m | % | m | % | m | % | m | % | m | % | m | % | m | % |
| Fusion | 1 | 88 | 1.26 | 95 | 1.41 | 87 | 2.09 | 98 | 1.23 | 99 | 1.38 | 99 | 1.40 | 94.33 |
| Combination | 1.77 | 88 | 1.27 | 91 | 1.01 | 93 | 3.31 | 67 | 2.43 | 93 | 0.98 | 95 | 1.80 | 87.83 |

**Table 1.** Average error obtained in meters and estimation accuracy for the localization of the target points using a real calibrated map and both algorithms with 3 Bluetooth APs and 4 WiFi APs.

Using a real calibrated map, the localization errors obtained with the fusion algorithm are smaller than with the combination one. The fusion method improves by 40 cm on average error the combination localization method. The estimation accuracy is greater with the fusion algorithm than with the combination one.

### 5.2 Localization results using a simulated power map

We have also tested the algorithms using a simulated power map. To construct this map, we have implemented a program using the Friis formula and empirical results, to simulate the power received from each WiFi and Bluetooth station for each point of the map. For that purpose, we formulate a propagation model that provides a relationship between the received power ($P_{RX}$) and the distance (d) between transmitter and receiver:

$$P_{RX} = A - 10\eta \log (d) \qquad (4)$$

In equation (4), A is a constant term and η is the path loss exponent.

We have also considered that walls introduce a different attenuation depending on the material they are made of. Using a PDA we have measured the attenuation produced by any different type of walls. As we can see in the figures 2 and 3, there are concrete walls and glass and plastic walls. The signal attenuation considered is 4dB and 1.5dB for Bluetooth, and 2.5dB and 1dB, for WiFi, respectively.

Based on the concepts of [16], some experiments have been made to compute the path loss exponent η and the constant term A of the Friis formula for a given transmitted power. A PDA has been used to measure the power values of the received packets, for different distances between transmitter and receiver. We have divided our map in different room areas. We have computed the values of the Friis formula, η and A, on each room area and with every technology independently.

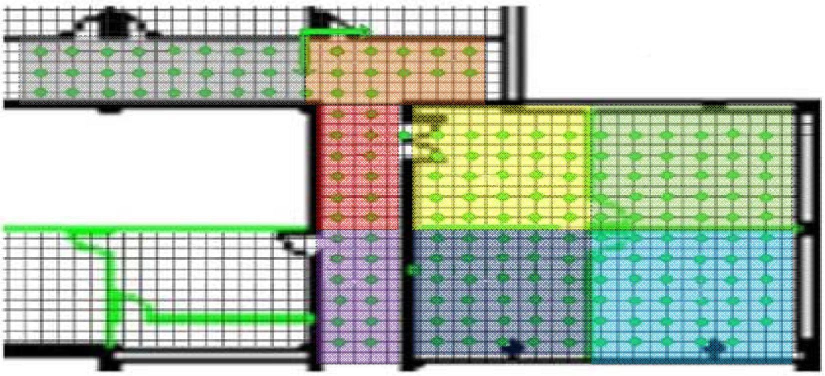

**Fig.** 5. Different room areas considered for the construction of the simulated map.

In Table 2 we summarize the average error and the estimation accuracy, obtained for the localization of several real target points using both algorithms and a simulated map. By average error we mean the average deviation for 100 measurements of each real target point. By estimation accuracy we mean the percentage of points obtained inside the room where the object is located.

| Method | Point 1 | | Point 2 | | Point 3 | | Point 4 | | Point 5 | | Point 6 | | TOTAL | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | m | % | m | % | m | % | m | % | m | % | m | % | m | % |
| Fusion | 1.99 | 80 | 2.19 | 87 | 2.34 | 72 | 1.61 | 100 | 3.37 | 54 | 1.40 | 99 | 2.15 | 82 |
| Combination | 1.66 | 76 | 1.34 | 91 | 1.64 | 66 | 2.17 | 87 | 3.71 | 77 | 1.32 | 97 | 1.973 | 82.33 |

**Table 2.** Average error obtained in meters and estimation accuracy for the localization of the target points using a simulated map and both algorithms with 3 Bluetooth APs and 4 WiFi APs.

Using a simulated map, the localization results obtained with both algorithms are very similar.

After comparison of the results obtained using a real calibrated map and a simulated map, we conclude that the average error and the estimation accuracy values obtained with the simulated map are close enough to those obtained with the real calibrated map. In particular, the average error using the combination algorithm with the simulated map is very similar to the error obtained using the real map. But the average error using the fusion algorithm with the real calibrated map improves by 75 cm the error obtained using the simulated map. Since the measurement of the real power received from every station for every point of the map can be very costly, the improvement obtained, in our case, with the fusion algorithm using the real calibrated map is not sufficient to justify the construction of the real map.

## 6 Conclusions and future work

We present in this paper two different algorithms, the fusion algorithm and the combination algorithm, to face the problem of indoor positioning using Bluetooth and WLAN technologies.

The fusion algorithm is based on the construction of a fusion map using WiFi and Bluetooth power values. Considering the three lowest values of a defined distance we compute the localization coordinates of the target point. The combination algorithm consists on the application of the first algorithm to two independent maps, one using only WiFi power values and another one using Bluetooth power values. Then, the results obtained with each technology are combined to obtain a final estimation point.

Some real experiments were done to locate a real target object. We compared the obtained results using a simulated map with a real calibrated one.

To construct the simulated power map we have divided our map in different room areas. We formulated a propagation model taking into account some real measurements on each room and with every technology independently. We have also considered the attenuation produced by walls.

Comparing both algorithms, it seems that using a real calibrated map with the fusion algorithm the localization errors are smaller and the estimation accuracy is greater than with the combination algorithm. While using a simulated map there is almost no difference between both algorithms.

Comparing the use of the real calibrated map and the simulated map, we can conclude that the improvement obtained using the real calibrated map is not sufficient to justify the construction of this real map.

In a future work, it would be interesting to design accurate models including other important factors such as interferences due to obstacles present in the covered area, multiple reflections. This will lead us to obtain a more accurate simulated map.

Research aimed at improving fingerprint method will be developed. Monitor APs that refresh the fingerprint database to improve its robustness, or the deployment of a Bluetooth ad-hoc network to add mobility to the Bluetooth APs are also being studied and considered.

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