A Smart-Phone Indoor/Outdoor Localization System

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***Abstract*—This paper depicts the operation of an integrated system designed for both outdoor and indoor localization, with special emphasis on the latter. It is demonstrated how three different methods of localization can be combined, based on WiFi access points and mobile cells. Not only there is no need to know the exact location of the access points to start using the system, but it also self-improves its own accuracy over time. The application developed to implement this method works on Android OS running devices and it is publicly available for download with the name "Locate Me".**

***Keywords*—Localization, Android, GPS, Wireless Networks, indoor positioning, WiFi, Locate Me**

I. Introduction

In past recent years there has been a rising usage of localization systems, both for personal and object tracking. The Global Positioning System (GPS) is the evidence of that. However, it has a determinant drawback: it works neither for indoor environments nor when surrounded by big structures. For this reason, alternative methods of localization have been studied.

At the same time and due to their decreasing cost, there are WiFi access points almost everywhere. It makes them very attractive to use in indoor localization systems.

There are many studies already made with different approaches using WiFi access points. One example of those methods is the localization by the roadside WiFi networks [1]. This method uses sectorized antennas to estimate the location of the access points. It is an accurate method but needs specific equipment to build the database. Other techniques of localization assume that the exact location of the access points is known and estimate the location of the mobile device taking into account the received signal strength [2]. They also use filters to minimize the fading effects that are predominant in indoor environments. A more complex method like SMART [3] uses other parameters besides WiFi signal to increase the accuracy of the results. They use the microphone, the camera and the accelerometer modules to measure additional information and create precise fingerprints.

In this work, we try to combine some of those techniques and develop a functional application for Android OS running systems. It was called "Locate Me".

It makes use of the GPS module to get the location of the device in outdoor environments, but when it cannot find signal (the GPS module does not return any coordinates to the operating system), it uses alternative methods to be located. These will be explained later.

In summary, it is a localization system to find friends wherever they are. The application sends the current location of the device to the server where it is stored. From that moment on, all friends can access this position and see it on the map.

A website where the users can register and see their locations is also available. It is a useful functionality to track mobile devices (see Fig. 1).

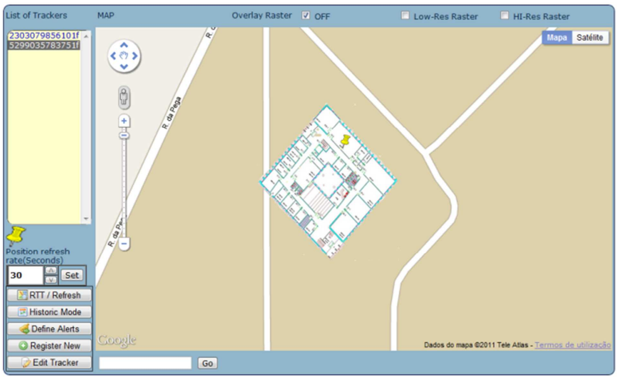

Figure 1. View of the website

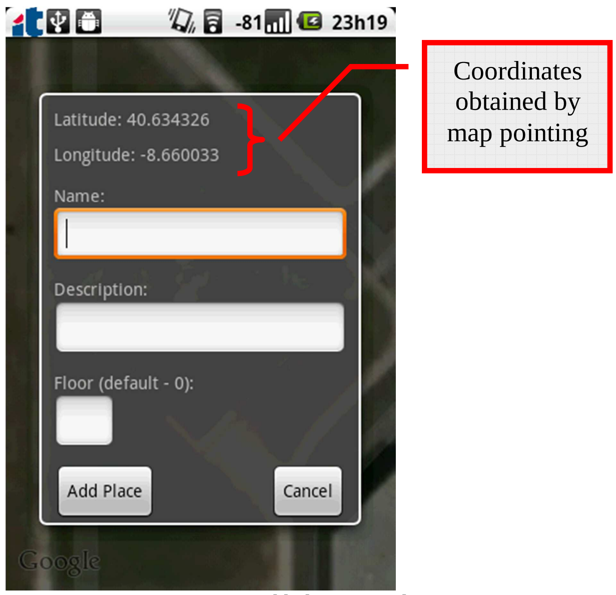

Figure 2. Add place example

One of the main advantages of the now proposed approach is that the users are allowed to add WiFi places to the database, which means that the locations' database can be updated manually, taking only into account the users' location input, the mobile cells and APs sweep (Fig. 2). This WiFi places works by selecting a position in the map, manually and adding a corresponding text tag.

II. Locate Me – Indoor/Outdoor Localization System

Locate Me is a practical application of outdoor and indoor location methods. It was developed for mobile devices running Android OS and takes advantage of the GPS and WiFi modules to acquire the location of a person. To represent the users' location it uses the Google Maps Android API and it has two views available: road view and satellite view (Fig. 3).

Figure 3. Map viewer

Besides that, there is an option to draw a building plan overlay in the map. For this reason, it is possible to get accurate representations of the users' locations, particularly inside buildings with a great number of WiFi access points and using the fingerprint localization method previously explained.

Fig. 4 shows an example of this type of representation:

In addition to those functionalities it is possible for the users to add friends in order to see their locations. They will also be represented on the map with  (see Fig. 4).

As a complement to the Locate Me mobile application there is also a website available. On the website it is possible to track your own devices by adding them to your account. There is a history mode where it is possible to see the last 100 positions.

III. Localization Alghoritms

This location system is based on 4 different methods of localization, one for outdoor and three for indoor environments.

As shown in Fig. 5, the first location method used (after a location request) is GPS. It works in open areas but fails when inside of buildings or just surrounded by them. To avoid these situations we developed 3 alternative methods of localization: localization by places' fingerprint, by geo-referenced WiFi access point and by geo-referenced cells. These requests can be configured with a minimum period of 10 seconds between each location request.

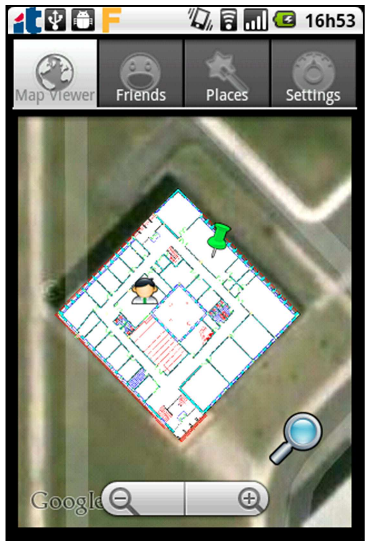

Figure 4. Locate Me print screen with plan

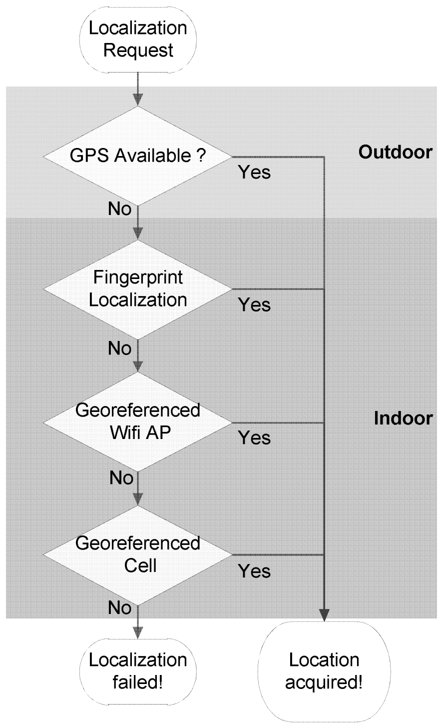

Figure 5. Localization request sequence

1) *Fingerprint localization*

The fingerprint method is an alternative localization method intended to be used in the absence of GPS signal. This localization process is initiated by the user, who points his current location on the map. The coordinates of this position will then be registered by the system. After that, the device performs a scan for WiFi access points and mobile stations. Finally, the result of this scan, the name, the description and the floor of this new location are sent to the database. This process is actually an initial calibration of the systems initiated by the user.

After the WiFi points are added to the database, they can be used to locate the devices, in order to do so the device perform a WiFi scan for 1 second and send the result to the server. This result includes the MAC address, the RSSI and the SSID of each detected access point. On the server side the access points are sorted by received power (RSSI) and after that, it uses the algorithm exemplified on Fig. 6 to try to find the best match between the WiFi scan result and the locations fingerprints in the database.

Fig. 6 shows how the algorithm works for a hypothetical scan result with 3 WiFi access points: AP_1, AP_2 and AP_3, with received powers of rssi_1, rssi_2 and rssi_3 respectively, and rssi_1 > rssi_2 > rssi_3 .

The algorithm searches for AP_1 in the location fingerprints. If it finds a match, it tries AP_1 and AP_2 simultaneously; if not, it skips the AP_1 and searches for AP_2. This algorithm works using a recursive function and as a result of that all access points found will be taken into account.

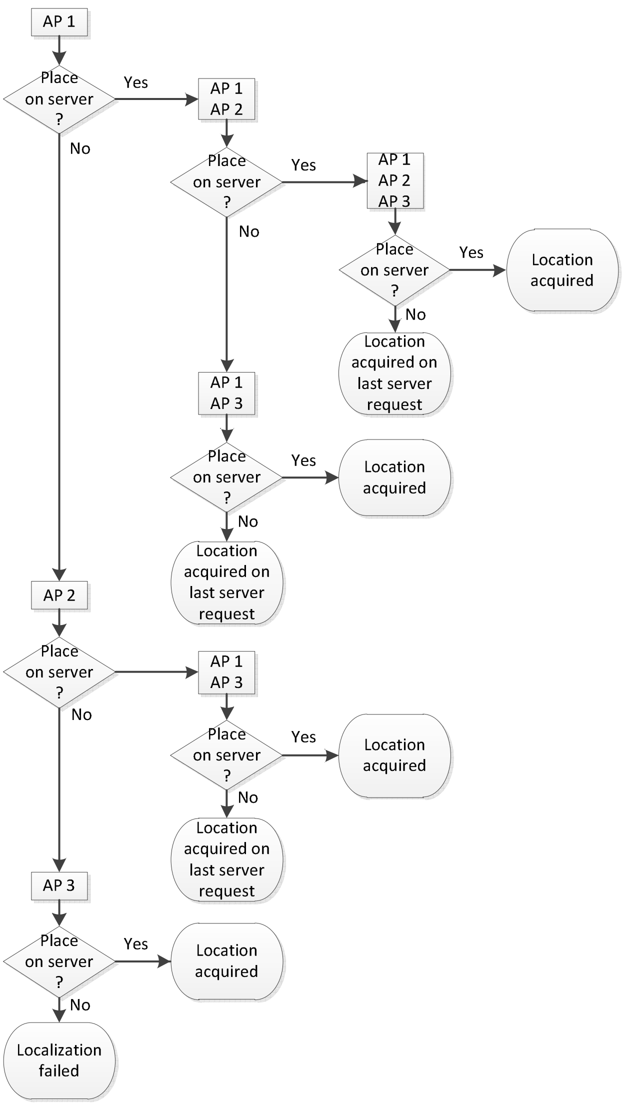

Figure 6. Fingerprint localization algorithm

2) Localization using georeferenced access points

Nowadays, nearly all mobile devices have simultaneously a WiFi module and a GPS module, so taking advantage of that we can create a database with geo-referenced WiFi access points. This database is automatically generated by the application and its precision is also improved with its use.

Every time there is a GPS signal available, the system performs a WiFi scan and sends the result with the GPS coordinates to the server. If a new access point was detected it will be added to the database. If not, and it already exists in the database its coordinates will be recalculated by the following method:

$$new\_upds = old\_upds + 1$$

$$new\_mean\_rssi = \frac{old\_upds \cdot old\_mean\_rssi + rssi}{new\_upds}$$

$$new\_pos = \frac{old\_pos \cdot old\_mean\_rssi \cdot old\_upds + pos \cdot rssi}{old\_upds \cdot old\_mean\_rssi + rssi}$$

old_pos – last calculated position of the access point;

pos – last position where access point has been detected;

new_pos – new position of the access point;

old_mean_rssi – mean value of the received signal strength;

$rssi$ – last received signal strength of the access point

new_mean_rssi – new mean value to the received signal strength;

old_upds – number of updates already made;

new_upds – number of updates already made plus the current update;

(*) All signal strengths should be in milliwatt;
(**) The coordinates of the access points (latitude and longitude) are both calculated by applying this method.

In brief, when an access point is detected, the new coordinates will be used in a calculation with a result proportional to the signal strength and the number of updates, approaching the previous position to the current one.

3) Localization using georeferenced mobile base stations

This type of localization is quite similar to the previous one. However, it provides a worse precision, since the covered area of a base station is bigger than the covered area of an access point. The number of detected cells by a smart-phone is usually much smaller than WiFi access points and subsequently the amount of distinguishable places will be reduced. This algorithm uses the same formulas of the "localization using access points" to determine the base station localization.

Even taking that into account this method should not be underestimated because in some situations it could be the only way to be located.

With a combination of these three localizations methods plus the GPS, it is possible to get a localization system for indoor and outdoor environments.

IV. DATABASE STRUCTURE

This application works close together with a database, the database is structured into four groups of tables specially designed for Locate Me application: users info, building plans, places fingerprints and geo-referenced access points.

1) Users info

In this section the information regarding users is stored. One table stores the name, status and the device ID of each user, another one stores the users locations history and finally ther is also a column to store the friendly relations.

This is the information shared with the website and used to display the users' positions on the map.

2) Building plans

In order to overlay the map with the building plans, there is a table where "PNG" images are stored together with the geographical information: left longitude, right longitude, bottom latitude, top latitude and floor. With this information it is possible to overlay the plan in the right place and with the right scale on a 2D map.

3) Places fingerprints

As a result of the fingerprint localization it is necessary to store the detected WiFi access points, their received power and where they were found. The name, the description and the floor of the place are also stored.

4) Geo-referenced access points

Two tables are used to geo-reference the access points, one for the WiFi access points and another one for the mobile cells. There is no private data stored on those tables. In case of WiFi access points it just stores the MAC (Media Access Control) address, the SSID (Service Set Identifier) and the RSSI (Receive Signal Strength Indicator).

V. CONCLUSION

In this paper we show that it is possible to build a robust localization system that works both in indoor and outdoor environments.

The indoor localization can be obtained using different complementary methods and for this reason the database can be self-constructed and improved by the users at the same time. As a result of the used methods it is not necessary to know the exact location of the access points to start using the localization system. In addition to this, the more it is used, the more accurate it gets.

After three months of the first version release it was possible to achieve about one thousand users all around the world. The users' dispersion can be seen on Fig. 7.

With the fingerprint localization method it is possible for users to add personal places to be located(for example different room in the house). The number of distighuishable places changes with the detected WiFi access points.

The geo-referenced WiFi access points and mobile cells registered in the database are also increasing and now there are over five thousand for WiFi and over four hundred for mobile cells. Fig. 8 and Fig. 9 shows these evolutions:

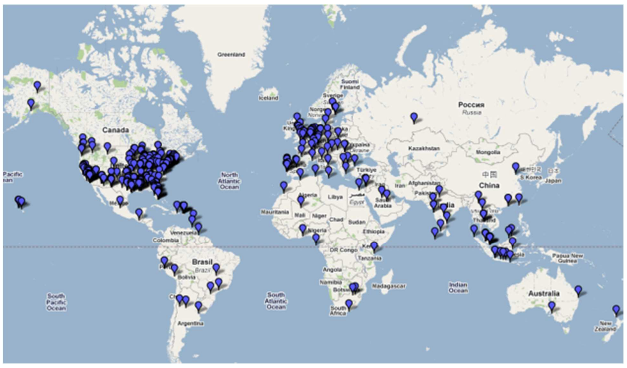

Figure 7. Locate Me users in the world

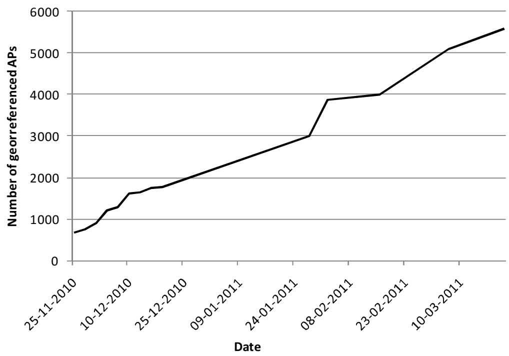

Figure 8. Georeferenced APs in the database

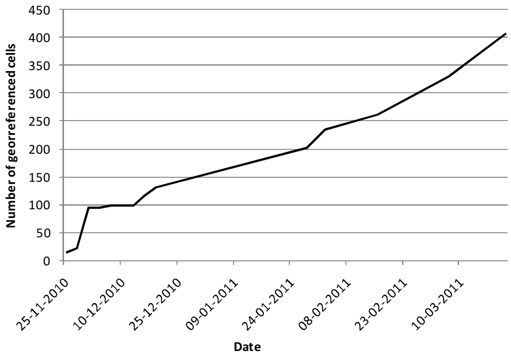

Figure 9. Georeferenced cells in the database

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