GeoWiFi: A Geopositioning System Based on WiFi Networks

Jaime Lloret, Jesus Tomas, Alejandro Canovas, Irene Bellver
Instituto de Investigación para la Gestión Integrada de Zonas Costeras
Universidad Politécnica de Valencia, Spain
jlloret@dcom.upv.es, jtomas@dcom.upv.es, alcasol@posgrado.upv.es, irbelser@upvnet.upv.es

Abstract—**GPS can only be used in outdoors where the satellite signals can be received, so it cannot be used to know the position of a device inside buildings. Cellular networks can be used to locate devices indoors, but the mobile phone network is owned by an enterprise, so a regular user is not allowed to know this information. So, new positioning systems are needed for urban zones and indoor locations. In this paper, we present a geopositioning system that uses public and private WiFi networks placed in cities in order to estimate the location of the user. Then we present the architecture of the system and the prototype implementation. Finally, we will show the developed protocol operation.**

Keywords-geopositioning; WiFi location; Wifi placement; WiFi tracking.

I. INTRODUCTION

Nowadays, the society demands new location systems to adapt the new services provided by the information technology, which demonstrates the acceptation and projection of the society in the Information Technologies. Some years ago, the Global Positioning System (GPS) [1] involved a revolution in the positioning systems (navigators, navy control, anti-thief systems, etc.). It is actually the most used positioning system in the world because it can be used worldwide. Its main features are:

- Global position thanks to a constellation of 30 satellites of the Army of USA.
- It is possible to include a random mistake for security reasons.
- There is a precision up to 5 meters.
- It is indispensable to have direct view from the devices to the satellites, so it cannot operate inside the buildings, tunnel, narrow streets, and in adverse atmospheric conditions.

However, although it is a mature system, this technology has an important limitation: it is not operative in indoors and places where there is a roof, and even in urban environments because a direct view to the satellite is required. GPS have several well-know limitations [2]. These limitations are found in:

- GPS signal reception
- GPS signal integrity
- GPS signal accuracy

GPS measurements are influenced by several types of errors: satellite errors, signal propagation errors, receiver errors and those provided by the GPS geometry. There have been several researchers with the purpose of solving GPS limitations.

Because the cellular telecommunications infrastructure is very large in urban zones, it can be used to locate mobile devices inside the cities and towns. Moreover, mobile phone networks offer mobile coverage inside the buildings. But cellular networks are owned by an enterprise, so a regular user is not allowed to know this information. Its main features are:

- The mobile device searches all cells that is able to connect with. This information is used to estimate its position.
- The system has high coverage and can be use in all places where there are mobile networks.
- It is cheap because it uses a network that is used for other purposes.
- It is quite imprecise, from 200 to 20.000 meters (depending on the number of cells). The precision is enhanced as a function of the density of cells.
- There are more precise systems that involve signal levels and delay times. Nevertheless, this information is only available by the mobile service operator.

Recently, a new location technology based on WiFi networks has been developed as an alternative. This technology uses the radio signals provided by all WiFi networks found in the urban zone in order to estimate the position of the device. In addition, the number of private and public access points is increasing in the cities and the WiFi coverage is getting higher, thus higher precision can be provided. Because WiFi networks can cross several walls, a continuous service can be offered in outdoors as much as building indoors [3]. The position based on WiFi has the following features:

- It works inside the buildings.
- The precision is variable and depends on the number of WiFi networks. It achieves up to 2 meters of accuracy.
- It requires a training phase in order to measure the signal level from a large number of geographic positions. The system could not run properly where the training process has not been performed.
- The set of signal levels measured in a moment is known as a WiFi pattern.

This new technology will favor a wide range of new applications oriented to people positioning and tracking. Recent studies show how a campus that has deployed a Wireless Local Area Network (WLAN), allow the network administrators to place the services in the most appropriate sites, and even the behavior of the people could be studied and their mobility tracked [4]. Otherwise, GPS technology is commonly used for cars with high mobility or pedestrian (when they are in rural zones or hill walking).

Positioning systems based on WiFi networks is a promising technology, but its deployment presents many Issues:

- The radio coverage of the access points depend on the walls crossed and on the obstacles in the in the line of sight between the emitter and the receiver. Moreover, in indoors, the power received in each point depends on many factors (even differs between different IEEE 802.11 variants) [5].
- Generally, where the WiFi access points are physically placed is unknown. Moreover, their position can vary dynamically, new access points could appear and others could disappear. Therefore, a training system or a baseline data is indispensable to characterize the network [6].
- There is not any WiFi position standard and normalized position processes in existence.
- It requires complex algorithms to locate a device starting only from radio signals. Nowadays, the research community is discussing on which is the most adequate algorithm [7].

In order to solve these issues and difficulties, some algorithms and specific and innovative processes should be developed. In this paper we will show a new geopositioning system based on public and private WiFi networks for urban zones. We have developed several algorithms in order to have an accurate system.

The remainder of this paper is structured as follows. In Section 2 we will discuss some existing related work. Our architecture is explained in section 3. Section 4 details the deployed prototype. The protocol operation is shown in section 5. Finally, Section 6 draws our conclusion and future work.

II. RELATED WORK

As we have stated before, the global positioning systems (GPS) are not efficient in outdoor places where there are buildings, because there are shadow areas where there is no satellite signal. This related work section has been split in three main parts. The first one shows WiFi positioning systems for outdoors. The second one shows some alternatives or proposals that combine GPS with WiFi and other technologies. The third one shows some indoor WiFi-based positioning systems.

Y. Cheng et al. evaluate the feasibility of building a wide-area 802.11 Wi-Fi-based positioning system in [8]. Then, they explore how a user’s device can accurately estimate its location using existing hardware and infrastructure and with minimal calibration. They evaluate the estimation accuracy of a number of different algorithms (many of which were originally proposed in the context of precise indoor location) in a variety of scenarios. Although the accuracy of their system is lower than existing positioning systems, it requires substantially lower calibration overhead than existing indoor positioning systems and provides easy deployment and coverage across large metropolitan areas. They conclude the paper letting us know that in dense urban areas Place Lab’s positioning accuracy is between 13–20 meters.

In [9], B. Li et al. analyze two WiFi positioning technologies for outdoors: trilateration and fingerprinting. Then, they carry out a fingerprinting study case in the Sydney central business district (CBD) area where WiFi APs are densely deployed. The fingerprint of a specific place can be used to identify the location. The key idea of the fingerprinting approach is to map location-sensitive parameters of measured radio signals in areas of interest. Their results show that the fingerprinting-based positioning system works well for outdoor localization, especially when directional information is utilized, with errors in the tens of meters. The same authors propose a location fingerprinting method in wireless LAN (WLAN) positioning in [10].

In [11], Amalina Abdul Halim developed an outdoor WiFi positioning system that can estimate the location of mobile devices based on the signal strength broadcasted by the access points. One of the main innovations of this work is the device location algorithm, which uses the K-NN algorithm (based on the nearest neighbor). A prototype was applied to the bus services of the University of Technology of MARA (UiTM), which allows estimating the location of the bus and the arrival time at the next stop.

Hereinafter we will see some positioning proposals that combine GPS with WiFi and other systems.

In [12], M. Weyn and F. Schrooyen combine WiFi localization with satellite-based navigation to form a WiFi-Assisted-GPS ubiquitous solution to make GNSS useful in urban and indoor environments. This combination is analyzed from a mathematical perspective. The WiFi location is based on fingerprints. To minimize the initialization and the training of the WiFi-positioning a self mapping system is needed.

The authors of the paper in [13] used the Time Difference of Arrival (TDOA) measurement, generated by the pseudorange observations of two visible satellites GPS with the WiFi fingerprint technology. The authors show that the integration of both technologies can improve the positioning accuracy by more than 50% when the method is applied.

In [14], Pornpen Ratsameethammawong and M. L. Kulthon Kasemsan study cell phone and WiFi positioning systems in environments where standard GPS fails. They focus their main research on a location system based on the Wi-Fi signals received from the existing hardware infrastructure of their University. They conclude that is better to use combined systems.

In [15], B. Li propose a client-based mobile phone location tracking by the combination of GPS, Wi-Fi and Cell location technology. Their proposal use vector calculations to track and locate mobile phones whereabouts are introduced. The combined methods make the tracking and locating of moving mobile phone more accurate and more effective despite the fact that GPS signal is not available.

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In [16], A. Kealy et al. study the potential of positioning WiFi to provide solutions in indoor environments. They present the practical results generated from a case study comparing commercial WiFi positioning systems.

Because indoor WiFi positioning systems have been studied in depth, we will show some methods, some of them published by the same authors of this paper.

The location systems in indoor environments have difficulties as the walls, interferences, multipath effect, humidity, temperature variations, etc. In [17], the authors describe two approaches where wireless sensors could find their position using WLAN technology inside a floor of a building. Both approaches are based on the Received Signal Strength Indicator (RSSI). The first approach uses a training session and the position is based on a heuristic system using the training measurements. The second approach uses triangulation model with some fixed access points, but taking into account wall losses and signal variations.

This idea of combining several positioning systems to locate a device is used in [18]. The authors proposed a new stochastic approach which is based on a combination of deductive and inductive methods whereby wireless sensors could determine their positions using WLAN technology inside a floor of a building. Their goal is to reduce the training phase in an indoor environment, but, without a loss of precision. They conclude their paper showing that their method is better than the existing ones.

None of the papers aforementioned use exclusively unknown WiFi access points to estimate the position of the devices in outdoors.

III. SYSTEM ARCHITECTURE

This section presents the architecture of the proposed geopositioning system. There are three main entities: the devices to be located (mobile devices), the one used to estimate the position (positioning manager), and the application infrastructure. It is shown in figure 1.

A. Mobile device

This is the device that is desired to be located. It is typically a mobile phone with a wireless interface, although it could be a PDA or a laptop. A software application will be installed in the mobile device. It will be running hidden and transparent to the user, so the device can be used regularly as a phone, PDA or laptop. It can be a device exclusively developed for location purposes. It can be included in a bracelet or a wristband, or could be embedded in any type of device that is wanted to be located.

The operation of the mobile device is as follows. It will connect to the positioning manager periodically and the positioning manager will reply with the information used for to estimate its location. This information consists on the radio signal strength received from several access points of the WiFi network (hereinafter called WiFi pattern). Optionally, the GPS position could also be sent if the device allows it and if the device is under several GPS satellites coverage. If the device is a mobile phone, it could also use a third location system: the location provided by the cells of the mobile phone providers.

B. Positioning manager

The main function of this entity is to geoposition the mobile devices by using the information received from them. It can also act as a database to allow the vertical software applications ask the position of any mobile device. The positioning system can be divided in three modules:

- Positioning module

The positioning server receives the positioning information from the mobile devices periodically. Using this information, the positioning module estimates the position of the device and stores it in a database.

Typically, this information consists of the signal strength level received from the access points that are closed to the mobile device. It could also receive the GPS position or the closest mobile cells.

In order to find the position from the WiFi signals, we use the algorithm described in [18], which has been developed by the authors of this paper. Its main drawback is that this method needs a previous training process, so it is only applicable when the mobile device is placed in a previously training area.

In the case of GPS, a positioning module is not needed because it directly provides longitude and latitude coordinates.

The mobile cells positioning case can only used if the device is a mobile phone. We have configured our system to use this option only if the others are not available. The information used to estimate the position is using the closest cells signals. We are aware that this method could have errors of about 100 meters [19]. Last research includes artificial neural networks in the location methods.

- Enquiry module

It provides service to the vertical software applications. It allows to ask the current position of a mobile device, or to ask for a historic list of its position. The information provided is the code of the device, longitude, latitude, high, accuracy estimation, time and date. This module will be implemented as a web service. XML documents will be exchanged using the HTTP protocol. The web service will be used by the vertical applications or by third parties.

- Training module

A training phase is indispensable for the positioning module, so it is performed in the training module. The WiFi patterns, jointly the position coordinates, are provided during this phase. Its purpose is to create a big database where a coordinate is associated with the received signal strengths.

The training process will be carried out in differently in outdoor than in indoor. In outdoor, a device with WiFi and GPS is needed. This device will be transmitting both GPS and WiFi data to the training module in the area to train. The indoor training process is more complex. It has to be carried out by a person that has to be indicating its position inside the building while it is shifting. A comparison between trilateration and training methods is shown in [6]. However, there are methods that let us estimate the position inside the buildings by using the training carried out outside the buildings. These methods are quite less accurate.

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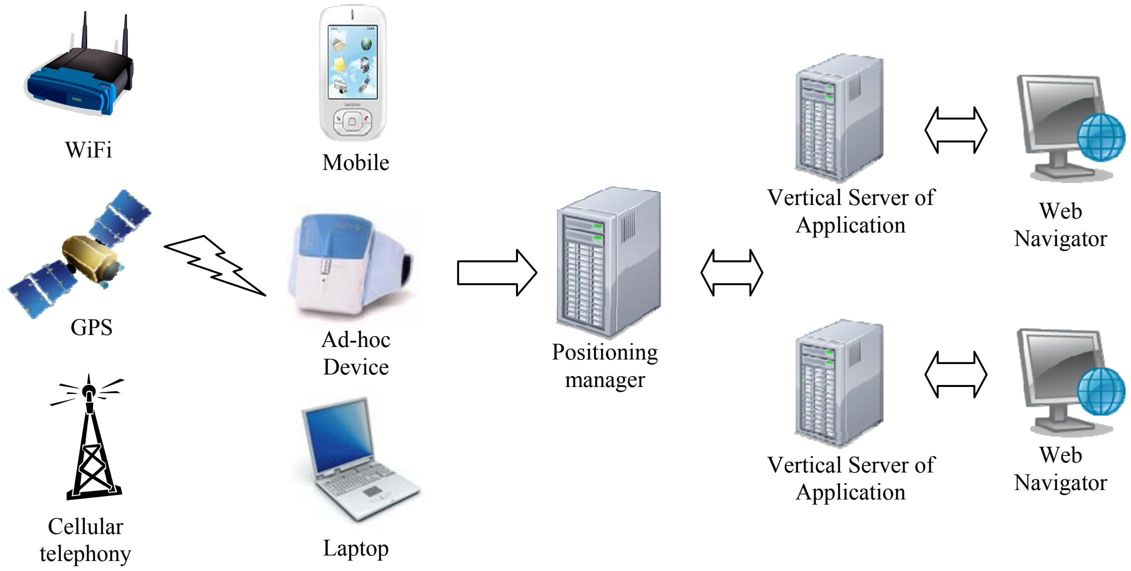

Figure 1. Positioning System Architecture

C. Applications infastructure

Each vertical application will have specific needs that will be solved in this entity. All software applications will acquire the positioning information using the enquiry module. The applications infrastructure is formed by an Apache Web Server (using PHP programming) and a MySQL database. We have used AJAX (Asynchronous JavaScript And XML) to create interactive applications in our system.

Figure 2 shows the architecture operation.

IV. PROTOTYPE IMPLEMENTATION

In this section we describe the elements needed to implement the prototype. As a basis the architecture described in the previous section will be used.

We have deployed two positioning devices with different features in order to cover higher number of applications.

A. Cellular Mobile Device

Nowadays, the cellular mobile device has become an indispensable tool in the personal communications. Thus, a location software application installed in the phone may open a wide range of new applications.

In order to use the device, it should have a WiFi interface and the software application should be compatible with the mobile phone operative system. In order to reach to a high number of mobile devices we have developed our software application to different operative systems. These Operative systems are the following:

- Microsoft .NET (Windows Mobile)
- Google Android
- Apple iPhone

Many mobile devices are able to obtain their location by using additional information sources than WiFi signals. The software application detects if the device has GPS and identifies the closest mobile phone cells (in case of a cellular phone). Then the device will send this jointly with the WiFi patters. This information is sent periodically to the positioning module in regular intervals which are configurable by the application and depends on the mobility of the user (larger time intervals will be used when there is less mobility).

B. Specific Device

There are many cases were a mobile phone cannot be used so another type of device is needed. Some examples are a positioning wristband or bracelet, or an anti-theft device. Because of it, a specific device for geopositioning is also needed in the market.

In this case we have chosen a SoC (Solution on Chip), from G2 enterprise [20], to develop the device. We used G2C543 Wi-Fi SoC model. It embeds a WiFi interface, a CPU and an I/O ports in a unique Chip. It has the following features:

- 32-bits CPU
- Internal memory: 128 KB RAM and 512 KB ROM
- A flexible interface for external sensors.
- An operative System with TCP/IP protocol stack, security and IEEE 802.11 b/g.
- A power management subsystem to save energy.

G2 enterprise has also a module called Epsilon Module Family PB which can be used with G2C543 to enhance its features [21].

- 8 Mb Memory Flash
- Low consumption WiFi Antenna.
- Real time clock.
- Power regulator for alkaline batteries.
- Reduced dimensions.

Table I shows a comparison of the main features of the two proposed devices for our geopositioning system.

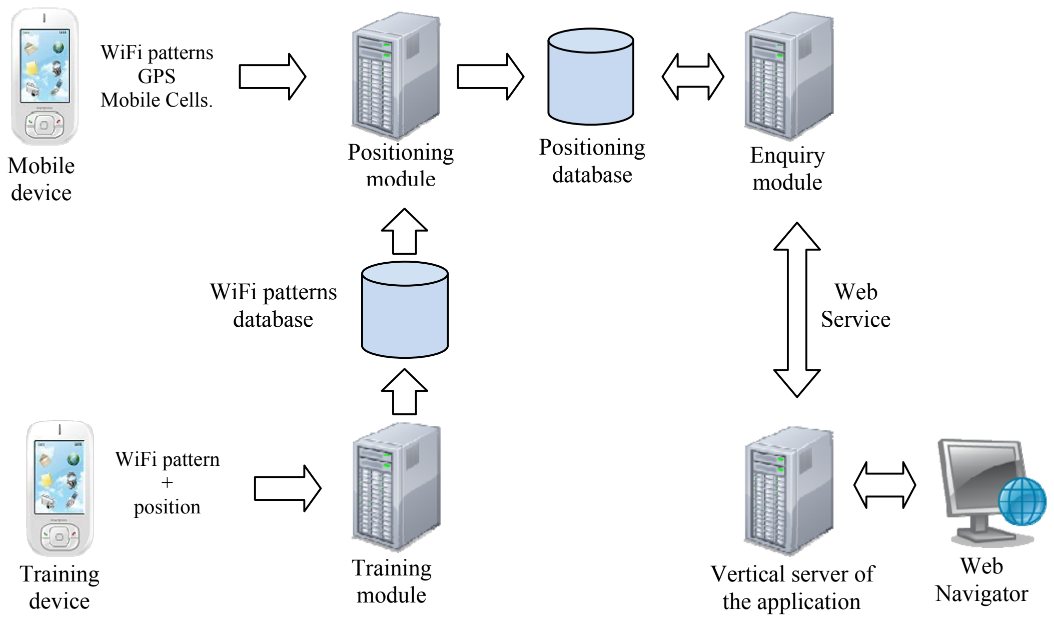

Figure 2. Iteraction between positioning manager modules.

TABLE I. DEVICE FEATURES COMPARITON

	Cellular Mobile Device	**Specific Device**
Type of device	Phone + positioning	Focused only on positioning
Coverage area	Medium city	Building or campus
Type of connection	Internet (GPRS/UMTS) + WiFi	Only WiFi
Application Examples	Teenager control / mobile workers …	Movement Control / equipment management

V. PROTOCOL OPERATION

In this section we describe the operation of the developed protocol. First, a user connects to the vertical server of application using a web navigator. This web page allows him/her to authenticate in the database or register as a new user. The web page is shown in Figure 3. When there is a new user, he/she must click on the "New User" button and Figure 4 appears. It shows the information needed for registration. This procedure allows registering himself. Then, the user must choose the group to join. So after being authenticated, it receives a popup asking for the joining group (see figure 5). This popup even allows creating a new group if the user will. Finally, if the device is not included in the system, it must be added by clicking in the "New device" button. Figure 6 shows the information that must be filled up to add a new device in the system. Only the users with enough privileges can add new devices to the system. If the device is yet added, this step is not needed because the system will know the device (each device has a unique WiFi interface MAC address which is also associated to a user or users).

Finally, after having filled up the user and the group and having the device recognized in the system, the GeoWiFi main window is opened (see figure 7). It shows the device list and a map with the placement of all devices in a group. We have programmed the application to reply some enquires. Thus, a user can know the last position for each device in its group. Moreover, the trace of a device can be also estimated. The map screen shows the placement of each device in real time. The "OK" button leaves the application.

A registered user, that is already registered in a group and is using a device that is included in the system, will follow the message flow shown in figure 8. Only four messages are exchanged between the Vertical server of the application and the user.

VI. CONCLUSION

In this paper, we have shown the implementation of a Geopositioning System Based on WiFi Networks. It uses the radio signal strength of the WiFi networks in order to estimate the position of the users.

The system uses a WiFi pattern method that allows having the most accurate system. Thus, a previous training phase is needed before setting up the system.

The developed system allows knowing the position or tracking teenager, mobile workers, and equipment movement.

We have shown the web pages used for authentication, registering and for displaying the information estimated by the system.

Our next step is to provide higher security in the user authentication procedure and to provide a intrusion detection system in order to grant access only original MAC addresses (not copied or cloned).

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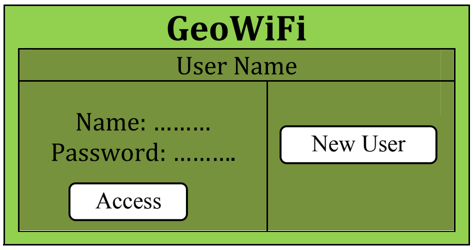

Figure 3. Firs access to the vertical server of application

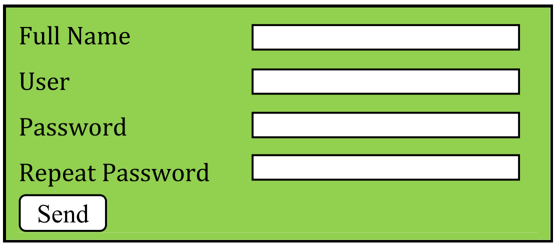

Figure 4. New user registration

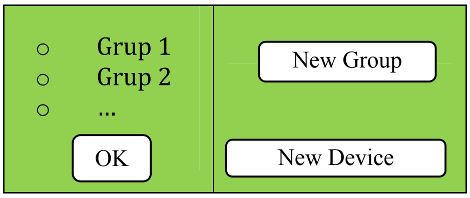

Figure 5. Group selection

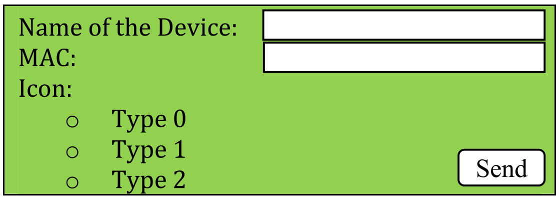

Figure 6. New device window

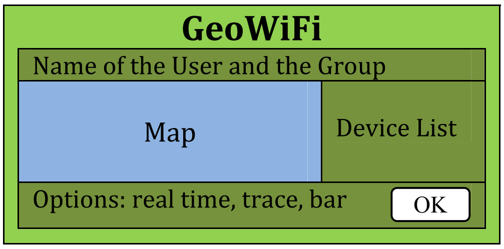

Figure 7. GeoWiFi main window

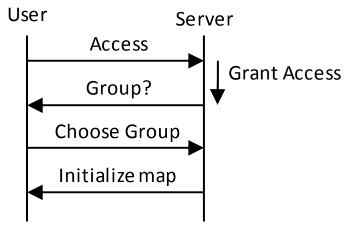

Figure 8. Messages Flow

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