

Devices Location in 802.11 Infrastructure Networks using Triangulation

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Abstract—Due to the great development in computer technologies and the popularity of WLANs, new services related to mobile computing can be developed. In this sense, location-based computing can be used by applications running in portable devices for taking better decisions and improving their performance. As the received signal strength (RSS) from several access points varies with position of device, we based on it for location determination of portable devices. In this paper, we present a location system for IEEE 802.11 infrastructure networks based on triangulation method. This system uses a SNMP framework to collect RSS in the portable devices and communicate it to a server where the location of devices is determined and available via http.

Index Terms—IEEE 802.11, devices location, received signal strength, triangulation, SNMP.

I. INTRODUCTION

Nowadays, the great development in computing devices and the recent advances in wireless technologies allow using portable computers in many situations of the daily life. One of the challenges of mobile computing is the tracking of the current location of users [1]. In this sense the location-based computing has made possible applications with the capability to sense their location and modify their setting and functions accordingly [2].

Many research initiatives have examined the problem of determining the user position using wireless data networks, such as IEEE 802.11. In these networks, indoor radio propagation is difficult to predict because of the dense multipath environment and propagation effects such as reflection, diffraction and scattering. It is due to the signal transmission path between transmitter and receiver is usually blocked by walls, ceilings, furniture, windows, etc. Besides, the user typically carries the portable device and due to the resonance frequency of water is at 2.4 GHz and the human body consists of 70% water, the wireless signal is absorbed and attenuated in user presence [3]. Therefore, a complete

propagation model that keeps in mind the complete geometry of the building and the random presence of users is a difficult and long time task [4]. For that reason, research works use a model based on signal strength and usually they work in two phases. During the first phase, normally termed *offline phase*, a database of the received signal strength (RSS) in each location is built. Then, in the second one (*online phase*), given a sample of RSS and a classification system which uses database information, the location is determined. Most of works differ in the latter phase. In [5] [6] [7] is used a data classification method based on support vector machine, neural networks and nearest neighbour search, respectively. Also, probability distributions are used in [8], and it is combined with clustering technique in [9] to reduce the computational requirements. Even so, these techniques can be heavy computationally and therefore they can introduce overhead in the computer. It has specially to be considered if it is designed for handheld devices where the processor power is not higher and the battery is a limited resource. For that reason, in this paper we present a centralized location system based on distance triangulation method to determine the position of portable devices. The portable devices do not estimate its location, they only sent RSS to a server, and then, it calculates the position of devices which can be queried via a web interface. In this way, users remotely can know the location of devices.

The rest of the paper is organized as follows. In section 2 we describe the location method. In section 3, we explain the architecture of our location system. Next, in section 4, we show experimental results. Finally, we sum up the conclusions and we present the future work.

II. LOCATION METHOD

IEEE 802.11 infrastructure networks are widely used in buildings as universities, schools, offices, etc. The access points used in this kind of networks are usually in a fixed position allowing communicating devices in a coverage area. If the position of three access points (vertices A , B , C of the triangle in Fig. 1) and the distances \overline{DA} , \overline{DB} and \overline{DC} are known, then a triangulation method can be used to infer D position [10]. This is done by finding the intersection of the three circumferences which centres are A , B and C vertices. Therefore, given coordinates of each access point (x_i, y_i) and distances from the portable device to each of them (d_i) , the position of a device can be obtained by the nonlinear system indicated in (1).

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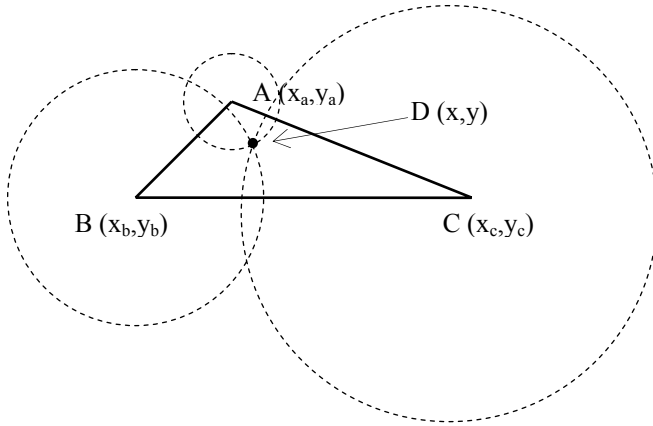


Fig 1. Triangulation method

In order to obtain the position of a portable device it is necessary to know the location of at least three access points. If two access points are known, then the system returns two possible solutions, and if only one access point is available, the possible positions are situated in the circumference with radius equal to the access point distance.

$$(x - x_i)^2 + (y - y_i)^2 = d_i^2 \quad (1)$$

$$i = a, b, \dots, n$$

To solve (1) is necessary to determine the distance from portable device to each access point. For doing that, we based on the path loss (transmitted power minus received power) which is given by the conventional distance power loss [4] as:

$$P = S + 10 \times n \times \log(d) + \sum L_w \quad (2)$$

where P is the path loss in dB, S is the path loss in dB to 1 metre from access point, n is the refractive index which depends on the propagation environment, d is the distance in metres between transmitter and receiver and L_w is the penetration loss when there are walls between transmitter and receiver. Therefore, given a RSS sample, we need to know the refractive index and the penetration loss to determinate the d distance using (3). These values have to be estimated in an empirical way for each access point because of they depend on the propagation environment and usually transmitters with different characteristics are used and located in different places.

$$d = \log^{-1} \left(\frac{P - S - \sum L_w}{10 \times n} \right) \quad (3)$$

Based on the previous information, our location method also consists in the two phases previously presented: offline and online. During the offline phase a refractive index for each available wireless network is obtained. To be able to obtain the value of n , many samples of RSS are collected at different locations for each transmitter and when there is only direct vision among transmitter and receiver. Next, from

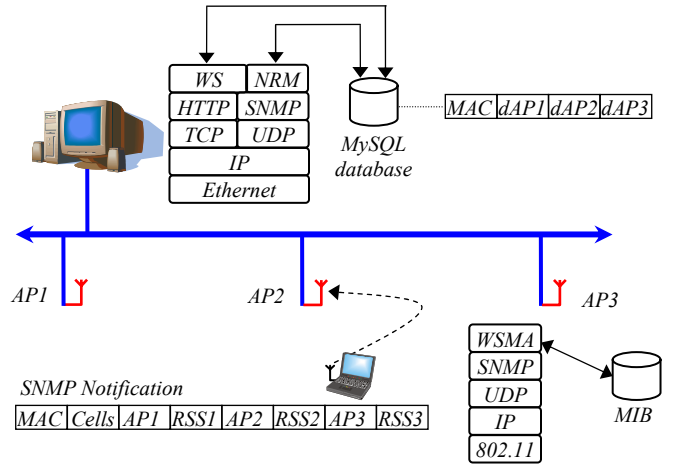


Fig 2. Location System Architecture

measurements and from (4) we estimate a refractive index for each access point and for each location. Then, an average refractive index is calculated. On the other hand, also in this phase the penetration loss is estimated. It is obtained by the difference between the RSS when the transmitter is in direct vision and the RSS when there are one or several walls among them. During the online phase location determination is carried out. For doing that, the RSS samples from each access point are used to estimate the distance from device to each access point using (3). Next, knowing the position of the access points and the distances from portable device to them, (1) can be solved.

$$n_{di} = \left(\frac{P - S}{10 \times \log(d_i)} \right) \quad (4)$$

III. LOCATION SYSTEM ARCHITECTURE

In this section we present our *Location System Architecture* (LSA) to determine the position of portable devices (Fig. 2). As any radio frequency location estimation system, LSA needs to monitor received signal strength from access points. For that, we based on our LAMGAC middleware [11]. LAMGAC uses a SNMP [12] framework for anticipating performance information of newly portable computers for load balancing on parallel computing. It presents a low overhead and easily it can be adaptive to our location system.

LSA is formed by two entities: a SNMP framework which monitors and informs about the wireless signal strength and a *Web Server* (WS) which estimates the position of devices solving (1). SNMP framework is formed by two entities: an extended SNMP agent termed *Wireless Signals Monitor Agent* (WSMA) and a manager named *Notifications Reception Manager* (NRM). In each portable device runs a WSMA which monitors received signals strength and sends a notification message to NRM with RSS samples. On the other hand, NRM is located where WS is running, although it can be located at any machine which can communicate with all portable devices and WS. This entity is in charge of decoding the received notification, estimating the distance from portable device to

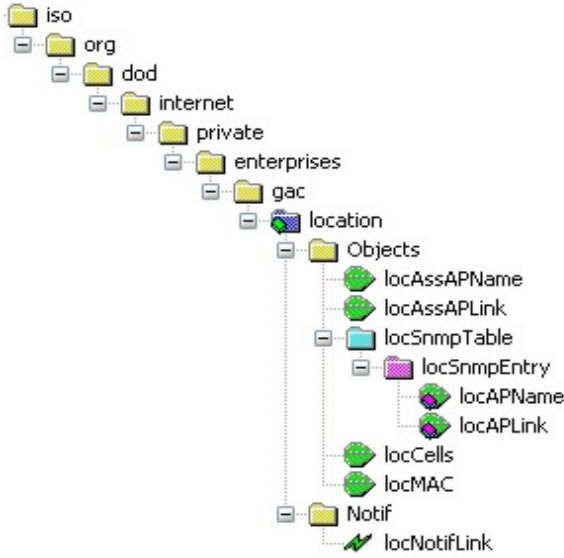


Fig 3. MIB of WSMA

each access point (3) and storing these values in a database for being available to WS. Next, we describe these entities.

A. Wireless Signals Monitor Agent

In order to implement WSMA we have extended the capabilities of the standard SNMP agent. We have designed an additional managed information base (MIB) to store the necessary parameters to location determination, and we have also built several functions to monitor the wireless signal. Fig. 3 shows the MIB tree and next each one of the parameters is described.

The *locAssApName* and *locAssAPLink* parameters store the name of the associated wireless network (ESSID) and the last RSS (dBm), respectively. The *locSnmptable* is a table where in each row is stored information about each available wireless network: name (*locAPName*) and the last RSS (*locAPLink*). The *locCells* parameter indicates the current number of available wireless networks. Finally, *locMAC* parameters store the MAC address of the network interface card (NIC). Except

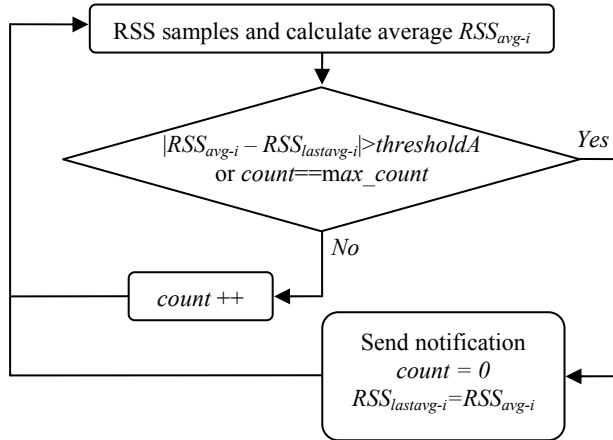


Fig 4. WSMA flow chart

the last parameter which is obtained when WSMA starts, the rest of them are monitored each second.

Regarding to the information sent to NRM, *locNotifLink* defines the notification type sent. We implemented a simple mechanism to decide when it is sent. Fig 4 shows this mechanism. A notification is sent when WSMA notes the portable device is moved, that is, when it receives consecutive different values of signal strength. Due to the RSS is not stable and changes every second [3], it is calculated the average value of last three RSS samples from each access point (RSS_{avg-i}). These values are compared when the average values sent in the last notification ($RSS_{lastavg-i}$). If the absolute value of one of these differences is greater than a threshold ($thresholdA$ in Fig. 4) the notification is sent. On the other hand, if all differences are smaller than $thresholdA$, WSMA supposes the portable device is static and no notification is sent. However, if this last condition is true during several consecutive times (max_count in Fig. 4), WSMA sends a notification to NRM. In this way, the network is not overhead when the portable device remains static and slow movements of devices can be updated. The *locSnmptable*, *locMAC* and *locCells* parameters and *count* variable (Fig. 4) are enclosed to the notification.

B. Notifications Reception Manager

NRM is in charge of processing the received notifications. The task carried out to process the notification messages is very light computationally. Simply, it extracts the enclosed parameters and calculates the distance from the portable device to each access point using (3). Then, it stores these values in a MySQL database together with MAC address of the computer NIC, so that the Web Server can access to them for solving (1).

Due to the received signal strength on the portable devices changes every second, the variation of distances calculated every time can be large, and therefore the location of them may be incorrect if the signal strength variation is too significant. To solve this problem, we proposed a simple but efficient strategy carries out by NRM. After the distances to each access point are estimated (d_{cur-i}), NRM calculates the absolute value of the difference between each d_{cur-i} and each distance stored in database (d_{sql-i}). If all differences are smaller than a threshold ($thresholdM$ in Fig. 5) the new distances are updated in the

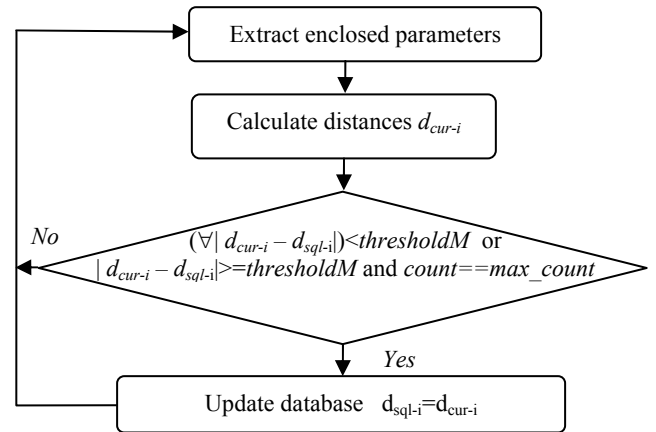


Fig 5. NRM flow chart

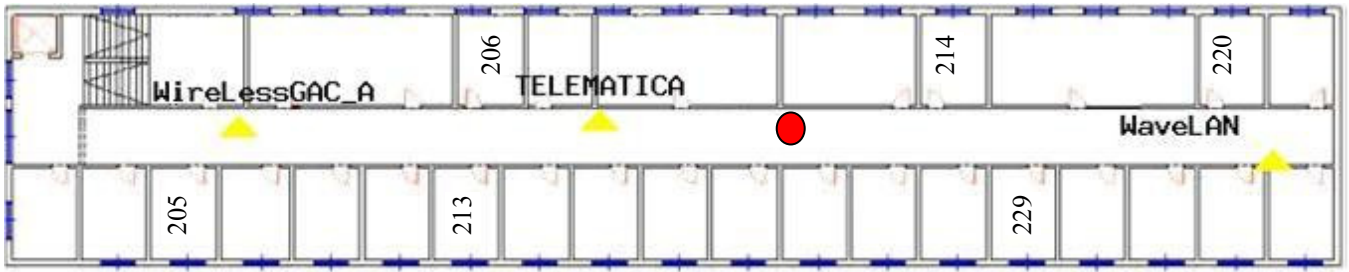


Fig 6. Layout of testbed floor

database. In other case, if any difference is greater or equal than the threshold, we temporarily consider that it is due to variation of signal strength because the device can not be moved a long distance in a short period. But if in this last situation the value of *count* variable (enclosed to notification) is equal to *count_max* constant we definitely consider that device has been moved more of the *thresholdM* metres. Therefore, the values of d_{cur-i} are updated in the database. Fig. 5 shows a flow chart of NRM when a notification is received.

This entity uses call-back mechanisms to gather notifications sent from WSMA. In this way, it only competes for resource usage with the WS when a notification message is received.

C. Web Server

In order to implement WS we programmed an Apache Web Server with PHP language. Basically, it permits to register new users and devices, to perform SNMP queries to devices and to location them in a given environment. Information about users and devices is stored in a MySQL database.

When a location request about a device is done, WS queries the distances to each access point stored in the database, and next, the nonlinear system (1) is solved. If three values of distances are available the exact position is found, and a red dot is drawn in the layout of the floor on web page (Fig. 6). However, if two distances are stored (wireless signal is only received from two access points) the solution of (1) returns two possible positions, and it is shown with two dots in the layout. Finally, if there is only a value, a circumference is drawn with centre equal to the position of available access point and radius equal to the distance to it.

IV. EXPERIMENTAL RESULTS

We performed our experiment in the second floor of the Telematic Engineering Department, University of Las Palmas de Gran Canaria. The floor has a dimension of 62 metres by 12 metres. The layout of the floor and the position of three access point (indicated with a triangle) are shown in Fig. 6.

Before testing our system, we have to configure it (offline phase). First, it is determined the refractive index and the penetration loss. In order to estimate the refractive index of each wireless network, we divided the corridor in cells of one metre long (62 cells in total). In each cell we took about 50 RSS samples from each access point and average value was calculated. Measures were made at different hours during several days and when there was only direct vision between

transmitter and receiver. From the average values of RSS and knowing the path loss to 1 metre and the transmitted power for each access point we calculated the refractive index in each cell using (4). Next, we estimated with these values the average refractive index. Low standard deviation was obtained. The values obtained are shown in the table 1.

Table 1. Refractive index from each wireless network

WireLess_GAC_A	1.65
Telematica	1.53
WaveLAN	1.88

On the other hand, the penetration loss because of the walls was also estimated in an empirical way. In the experiments carried out in our testbed environment, we realized that if the received signal strengths from all access points are minor than a determined threshold (-59 dBm) there is a wall in the signal path, and if the signal strengths are minor than another threshold (-80 dBm) there are two or more walls. In direct vision the received signal strengths from all access point is always greater than -59 dBm. The values of penetration loss are shown in the table 2.

Table 2. Penetration loss (dB)

ESSID	1 wall	2 or more walls
WireLess_GAC_A	15.5	31
Telematica	15	24.75
WaveLAN	19.5	23.4

Finally, *thresholdA*, *thresholdM* and *max_count* are fixed to 2 dB, 10 metres and 3, respectively. After configuring NRM and WSMA we can test the environment. Tests were done in two categories: a) in the corridor, and b) in the offices.

A. Corridor

In order to evaluate the accuracy of the location system in the corridor, we moved the portable device from the corridor's entrance to onwards taking measurements every two metres. At each position and at different time, location web page of WS was invoked about five times whereas portable device remained static during at least three seconds. Besides, in the corridor is always received signal strength from all access points and therefore, the solution of (1) returns the unique possible position. Fig. 7 shows the location determination at

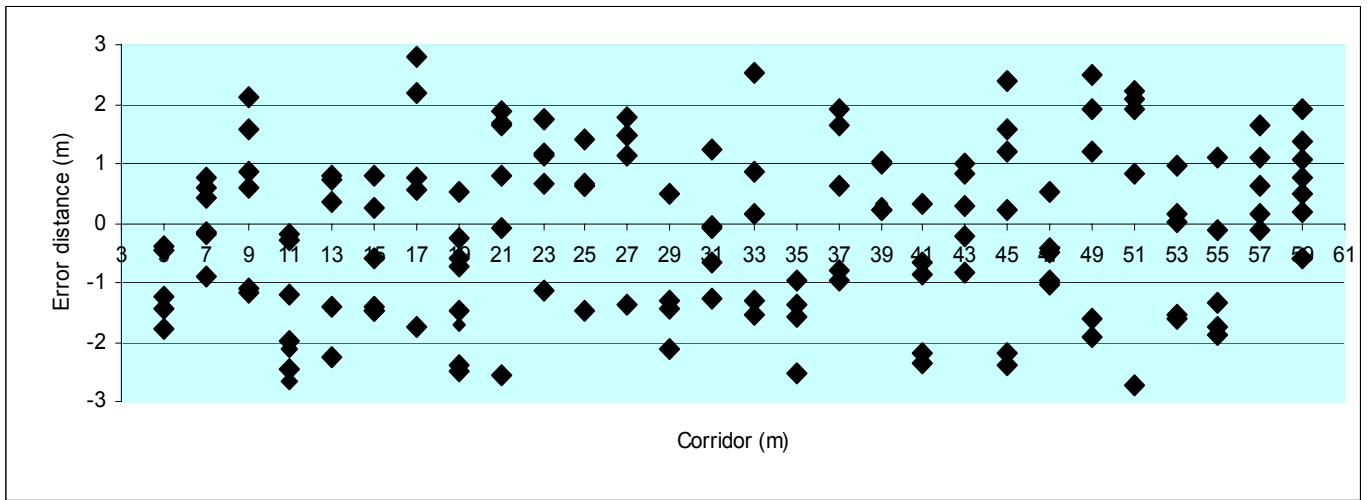


Fig 7. Error distance in the corridor

each position. As it can be seen, maximum error distance is less than three metres; it represents about 5% with regard to the length of the corridor. Besides, the position is determined with an error distance smaller than 2.5 metres with a 96% of success. Table 3 shows the success probability according to distance ranges.

Table 3. Success probability in the corridor

Error Distance(m)	Probability
$x < 1$	45
$1 < x < 2$	40
$2 < x < 2.5$	11
$2.5 < x < 3$	4

B. Offices

In order to evaluate the accuracy of the location system in the offices, we positioned the portable devices in the centre of several rooms. In all offices the RSS is only available from two access points. Therefore, the nonlinear system returns two possible solutions; one of them should be inside the correct office and another should be within the opposite room. Table 4 shows the success percentage when location web page of WS was invoked and one solution was within of the correct office. When the position of portable device is estimated out of room, it is located in the next room. It only represents about four metres, but there is a wall between the estimated and correct position.

V. CONCLUSION

In this paper, we presented the design and evaluation of a location system of portable devices in IEEE 802.11 networks. The location technique is based on triangulation method and a SNMP framework for gathering the received signal strength. Experimental results show that location system has accuracy about of 96% within 2.5 metres. However, it is obtained when three access point are available in the position to test; in another case the accuracy is reduced. For that reason, in our ongoing

work we are planning to design a new technique to improve these results, by combining the triangulation method with probability distributions of received signal strength.

Table 4. Success probability in the offices

Office	Probability
205	67
206	63
213	95
214	67
220	90
229	71

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