

# Effectiveness and Accuracy of Wireless Positioning Systems

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**Abstract:** - Localization or positioning is an important aspect of mobile applications in order to achieve context-aware applications. The main goal for localization process is estimating the position of a mobile device in its environment based on a set of sensors with known positions. Modern mobile devices produced nowadays, and almost all smartphones and PDAs, have one or more wireless communication interfaces in order to communicate with other devices. WLAN infrastructure is a widely accepted and implemented communication standard in many indoor environment, therefore many buildings are already equipped with IEEE 802.11 WLAN infrastructure access points. Wireless adapters the modern mobile devices are equipped with can monitor radio power strength of the emitting sources nearby. Based on the received radio signal strength an estimation of distance between the device and power source can be computed. In this paper we want to describe and conclude our work regarding the possibility to design a simple and energy efficient positioning solution to be implemented on mobile devices with limited resources.

**Key-Words:** - wireless positioning systems, radio signal strength, energy efficiency, trilateration

## 1 Introduction

One of the most significant elements of context-awareness in ubiquitous environments is mobile device localization. To obtain the accurate location information for indoor environments is a challenging problem; therefore there have been a number of attempts to design systems for indoor localization using different wireless sensing techniques. Signal strength (SS) approaches are easy to implement in the existing technologies in mobile devices. We want to investigate the positioning methods based on the trilateration scheme with a simply and clearly mathematical model.

Localization or positioning is an important aspect of mobile applications in order to achieve context-aware applications. The main goal for localization process is estimating the position of a mobile device in its environment based on a set of sensors with known positions. Modern mobile devices produced nowadays, and almost all smartphones and PDAs, have one or more wireless communication interfaces, like bluetooth or WiFi, in order to communicate with infrastructure computing systems or other mobile devices. WLAN infrastructure is a widely accepted and implemented communication standard in many indoor environment, therefore many buildings are already equipped with IEEE

802.11 WLAN infrastructure access points [1]. Wireless adapters the modern mobile devices are equipped with can monitor radio power strength of the emitting sources nearby. Based on the received radio signal strength an estimation of distance between the device and power source can be computed. If a mobile device can monitor at least three WLAN power signal sources with a-priori known positions, an estimation of the mobile device position can be achieved. This approach has the advantage that no costly hardware installations are necessary inside the building, nor additional sensors to be attached with the mobile devices [2].

Many mobile applications would benefit from being able to use WLAN for communication as well as positioning [1]. Determining the physical location of mobile active indoor nodes, can be one of the main issues of a new class of applications and position-dependent services in ubiquitous systems. For example only localization applications for ubiquitous systems will have a growth of value (8 times in 5 years) from 1 billion USD in 2005 up to 8.5 billion USD in 2010 [3]. Hence we can say that we shall face with a pronounced development of the number of applications that run on such devices and use different positioning techniques.

The goal of this paper is to evaluate the possibility to implement a simple wireless positioning systems using only trilateration. The main requirement in developing such a software solution is low computational power resources usage and the second one is to have minimum impact on power consumption.

This paper is structured as follows: in next section the related works on positioning systems are presented. The proposed mathematical model variants are described in section 3. The framework architecture for wireless positioning is described briefly in section 4. The experimental test cases and their results are presented in section 5. Finally we conclude the paper in section 6.

## 2 Related Work

In the literature there are many approaches for designing methods for positioning systems, which are different in terms of distance measurement techniques and mathematical models.

There are a few different localization methods that can be used for the positioning procedure. These methods are divided into three major categories based on the environment in which the information is spread: indoor, outdoor or mixed. Positioning systems consist of algorithms and methods to estimate the position of an unknown target, and are classified based on [4]:

- the signal types:
  - o infrared,
  - o ultrasound,
  - o ultra-wideband, and
  - o radio frequency
- the signal metrics
  - o global location systems - outdoor methods
  - o cellular location systems - mixed methods
  - o indoor location systems.

The most popular outdoor localization system is known as GPS (global positioning system). The GPS receiver calculates its current position (longitude, latitude, elevation) using a trilateration technique. The distance is computed based on the time delay between the transmission and reception of the encrypted radio signal issued by the satellites.

In comparison with these systems, the indoor system poses additional challenges. In our work we address the indoor positioning problem. Different techniques exist for estimating the position of a mobile device in a wireless network [1]:

- cell based - with this localization technique the position of a device is simply located around the position of the access point where the device is connected.
- signal propagation time based - the position is determined using the time of arrival of the received signal from several access points (APs) to the target device.
- signal angle of arrival - the position of a device could be estimated based on the measured angle of arrival of received signal from surrounding APs.
- receiver signal strength based - the position of a target device is estimated using the received signal strength from surrounding APs.

Cell based positioning method is very simple and considers that a mobile device is located near the known position of the AP this device is connected to. Despite its simplicity this method is not largely used because of the lack of accuracy.

The propagation time can be directly translated into distance, based on the known signal propagation speed [5]. Based on signal propagation time from surrounding APs to the target device, its position can be estimated. These techniques offer increased accuracy but they require precise clock synchronization and more expensive infrastructure. There are two important methods in this category: ToA (Time of Arrival) [6] and TDoA (Time Difference of Arrival) [7]. The most important parameter for accurate indoor positioning systems is the time of arrival TOA of the Direct Line of Sight path [8]. Therefore an accurate estimation of TOA from received communication signals is required.

Angle measurements can be used for indoor positioning using AoA (Angle of Arrival) of the received signal or DoA (Direction of Arrival) [9, 10]. For this technique additional hardware is also needed in order to measure the angle of incidence of the received signal. The AOA requires antenna arrays at each node which increase the complexity of the existing system, as well as, performing worse in multipath environment [7].

The fourth solutions class for indoor positioning system is based on received radio signal strength of the surrounding APs. This positioning method uses the existing WLAN infrastructure and does not need any extra hardware attached to the target device. The network card in the mobile device continuously measures the RSSI (Radio Signal Strength Indicator) of the APs in its neighbor. This information is available due to beacon broadcast multiple times per second by every AP [2]. Based

on RSSI the mobile device can estimate the distance from its position to the AP it measured the RSSI. Using at least three APs with well known positions, a mobile device can estimate its position based on measured RSSI from these APs.

RSS based WPS (Wireless Positioning Systems) were studied a lot in the last years. There are at least three location algorithms in this class of WPS:

- fingerprinting (RSS patterns [2, 11, 12])
- simulation (lines of constant RSS [1, 13])
- trilateration (Euclidian distance extracted from RSS [14])

The fingerprinting method is the most common used for WPS. An estimate of the target device position is obtained from the RSSI measurements and using a radio signal propagation model inside the building [2]. The propagation model can be obtained using a priori RSS measurements in different locations in the building. These measurements compose a RSS map, called fingerprint, are stored in a database and can further be used to estimate the position of a target device. This method is divided in two phases [1]: initial calibration phase where the RSS map is achieved and the positioning phase, the measured RSS values from surrounding APs are compared to the ones stored in the database in order to estimate the current position of the device. The disadvantages of this approach are the database generation and maintenance requirements [11]. During the WPS lifetime, every change in the infrastructure requires the build of the RSS map.

The second class of WPS methods uses simulation algorithms to build the propagation models of the radio signal inside the building. The simulation starts from the building map and positions of APs on the map. During the simulation for every AP the lines of constant RSS, called isobars, are computed. After the simulation the map of RSS isobars for every AP is obtained. This map can be further used by a mobile device to estimate its position inside the building. The drawbacks of this method are the complexity of the propagation model simulator and the computation resources needed to run the simulation algorithms.

A network-based localization method is presented in [15], which uses the radio propagation signal strength that covers a 2D plane, where three sniffers are placed in order to listen to a single signal strength emitted by the mobile and to automatically generate an estimated signal strength

map. Also, the algorithm is able to establish the mobile's position by browsing this table.

Unlike the previously described method a client-based localization solution is presented in [16], using radio-frequency (RF) as well, in which the main element is recording and processing the signals received from several base stations that are placed by overlapping coverage in the 2D plane. The triangulation is achieved by using two methods: the first one requires measuring the signals and creating a signal strength map SS-MAP and searching the best signal strength measurements; the second method requires the usage of a simple propagation model in order to estimate the SS-MAP.

The authors of [2] developed and tested a software framework called "ipos" for indoor positioning based on WLAN fingerprinting the can by used to build location based applications. It consists of an efficient, freely configurable framework, which is suitable for multiple application architectures. The RSS measurements are performed on the mobile device, the computation and visualization of position can be run on an infrastructure server or on the device itself. Based on their tests they obtained an accuracy of better than 3 meters for an area of 1500 m<sup>2</sup> covered by 7 APs.

The authors of [1] developed a method to identify intersections of lines of constant RSSI values, called isolines, of several APs within interpolated radio maps based on triangulation. Based on their tests an average deviation of 3 meters was obtained for 330 m<sup>2</sup> exhibition room equipped with 4 APs.

The aim of the work presented in paper [17] is to study the possibilities that the WLAN's offer to indoor localization and to implement an application that will help to localize a device equipped with a WLAN's card supporting the IEEE 802.11b protocol. The application developed by the authors called Wlib uses a database with signal strength values stored and a mathematical model in order to estimate the position of a user with a wireless device into a library of their University.

The third RSS method is based on trilateration [14]. This approach is simple, easy to implement and needs fewer resources to compute the position. This method is appropriate for a mobile device where the energy and computational resources are limited, even the accuracy of the method is in the best case comparable with the other methods.

The disadvantage of all RSS methods is the random deviation from mean received signal strength caused by shadowing and small scale

channel effect [7]. We consider based on our tests, that the accuracies obtained by other positioning applications are the best that can be achieved and in the real life usage scenarios the positioning accuracy will decrease significantly due to: changes in the environment, people moving around in the measured environment, mobile device speed and orientation, APs radio signal transmitter's fluctuations, etc.

Power consumption and energy efficiency are an important aspect for mobile applications in general and for local positioning application in special. Therefore one of the topics we investigate in this paper is the energy efficiency of WPS applications. The power consumption problem of mobile systems is in general a very complex one and remained of interest for quite a long time [18, 19]. In this paper defined a software execution framework for mobile systems in order to characterize the power consumption profile of different types of mobile applications [18].

Our goal is to investigate how trilateration can be used in indoor positioning, to estimate its accuracy and its needed resources for the mobile devices. We target positioning in large rooms with different objects inside the room and people moving inside the room. We also want to be realistic and provide also the problems such a positioning system implementation will face during its exploitation. This paper covers our work in last three years partially presented in some conference papers [14, 20, 21, and 22].

### 3 Mathematical model

The trilateration assumes the existence of at least three access points (APs) with known positions. The distance between each access point (AP) and the mobile device (MD) have to be determined by computations. For every distance a circle can be drawn. In the ideal case, these three circles must intersect in a single point which is actually the position of our mobile device (MD).

The method chosen for obtaining the distance between AP and MS is based on the signal strength (SS) measurement [22]. The propagation of radio waves is influenced by three factors: "free space loss", attenuation by the objects on the propagation path, and the signal's scattering. In the absence of obstacles, the model for propagation is "free space loss" which can be expressed for the ideal isotropic antenna as in (1):

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2} \quad (1)$$

$P_t$  – signal power at the emitter

$P_r$  – signal power at the receiver

$d$  – propagation distance between emitter and receiver

$\lambda$  – carrier wavelength

$f$  – carrier frequency

$c$  – speed of light

The ideal situation, when there's no obstacle, we consider the bi-dimensional case when all APs and the mobile device are in the same plan. If no perturbations interfered along the measuring, at moment  $t$ ,  $M$  receives a signal with  $P_i$  power from the transmitter  $AP_i$ . The distance between  $M$  and  $AP_i$  could be calculated with the formula (2):

$$d_i = \sqrt{\frac{P_{ti}}{P_{ri}}} \left( \frac{c}{4\pi f} \right) \quad (2)$$

In the real world, measuring SS is made with some errors, because the SS cannot be determined with very high precision, even in the case of obstacle absence. If we take into account the attenuation induced by some obstacles the problem could be more complicated. Hence the intersection of the three circles is not a single point. For three access points the maximum number of points is six, because every two circles can generate two points of intersection.

The ideal situation, when there's no obstacle, we consider a bi-dimensional case. If no perturbations interfered along the measuring, at the  $t$  moment,  $M$  receive  $P_1$ ,  $P_2$  and  $P_3$  from the 3 transmitters  $AP_1$ ,  $AP_2$ ,  $AP_3$  respectively. So, it is at:

$$d_1 = \sqrt{\frac{P_{t1}}{P_{r1}}} \left( \frac{c}{4\pi f} \right) \quad (3)$$

from the transmitter  $AP_1$ ,

$$d_2 = \sqrt{\frac{P_{t2}}{P_{r2}}} \left( \frac{c}{4\pi f} \right) \quad (4)$$

from the transmitter  $AP_2$ ,

$$d_3 = \sqrt{\frac{P_{t3}}{P_{r3}}} \left( \frac{c}{4\pi f} \right) \quad (5)$$

from the transmitter  $AP_3$ ,

The receiver is at the intersection of the circles having the centre in  $AP_i$ , of radius  $d_i$ , because in every point of a circle the same power is intercepted. In ideal case, the intersection of the 3 circles is one point only, which is M (Fig. 1).

$$M : \begin{cases} (x_M - x_{AP_1})^2 + (y_M - y_{AP_1})^2 = d_1^2 \\ (x_M - x_{AP_2})^2 + (y_M - y_{AP_2})^2 = d_2^2 \\ (x_M - x_{AP_3})^2 + (y_M - y_{AP_3})^2 = d_3^2 \end{cases} \quad (6)$$

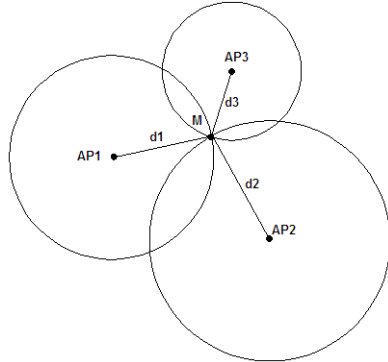


Fig. 1 Position of M in 2D ideal case

If we accept that the signal reaches the receiver influenced by some perturbations, then the intersection of the circles is no longer a circle but a domain as in the Fig. 2.

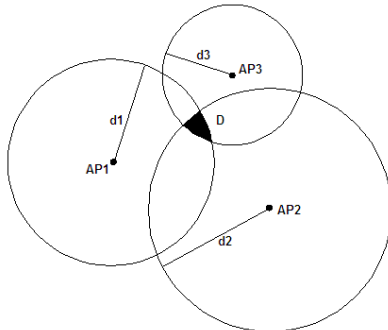


Fig. 2 The 2D real case

Domain D can be estimated to one point considering this point its centre of mass and it can be considered that the approximate position of M.

$$D : \begin{cases} (x - x_{AP_1})^2 + (y - y_{AP_1})^2 \leq d_1^2 \\ (x - x_{AP_2})^2 + (y - y_{AP_2})^2 \leq d_2^2 \\ (x - x_{AP_3})^2 + (y - y_{AP_3})^2 \leq d_3^2 \end{cases} \quad (7)$$

The coordinates of the centre of mass are:

$$x_M = \frac{\iint_D x \rho(x, y) dx dy}{\iint_D \rho(x, y) dx dy} \quad y_M = \frac{\iint_D y \rho(x, y) dx dy}{\iint_D \rho(x, y) dx dy} \quad (8)$$

$\rho(x, y)$  being the density of the environment in the point  $(x, y)$

In the three-dimensional case, in the ideal variant when there are no perturbations in intercepting the signal, and the signal does not meet any obstacle, the receiver is the intersection of the spheres with the centers in  $AP_1$ ,  $AP_2$  and  $AP_3$  of radiant  $d_1$ ,  $d_2$ , and  $d_3$  respectively, given by the (3), (4), (5) relations.

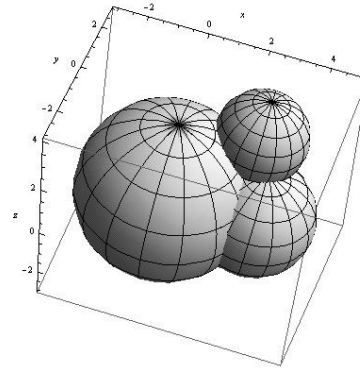


Fig. 3 The 3D case

In the real case, where perturbations appear at the interception of the signal, the intersection of the four spheres will be a D domain which also is reduced to its centre of mass, as it is shown in:

$$D : \begin{cases} (x - x_{AP_1})^2 + (y - y_{AP_1})^2 + (z - z_{AP_1})^2 \leq d_1^2 \\ (x - x_{AP_2})^2 + (y - y_{AP_2})^2 + (z - z_{AP_2})^2 \leq d_2^2 \\ (x - x_{AP_3})^2 + (y - y_{AP_3})^2 + (z - z_{AP_3})^2 \leq d_3^2 \end{cases} \quad (9)$$

$$x_M = \frac{\iiint_D x \rho(x, y, z) dx dy dz}{\iiint_D \rho(x, y, z) dx dy dz} \quad y_M = \frac{\iiint_D y \rho(x, y, z) dx dy dz}{\iiint_D \rho(x, y, z) dx dy dz} \quad z_M = \frac{\iiint_D z \rho(x, y, z) dx dy dz}{\iiint_D \rho(x, y, z) dx dy dz} \quad (10)$$

$\rho(x, y, z)$  being the density of the environment in the point  $(x, y, z)$

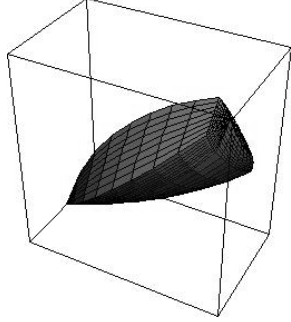


Fig. 4 D domain for the 3D case

This centre of mass approximates the position of M. In order to resolve this problem of trilateration we propose two geometric methods.

#### Method I

In the ideal case, the solution is generated by the following system of equations [21]:

$$M : \begin{cases} (x_M - x_1)^2 + (y_M - y_1)^2 = d_1^2 \\ (x_M - x_2)^2 + (y_M - y_2)^2 = d_2^2 \\ (x_M - x_3)^2 + (y_M - y_3)^2 = d_3^2 \end{cases} \quad (11)$$

Where,  $(x_M, y_M)$  are the mobile node's coordinates,  $(x_i, y_i)$  are the AP's coordinates and  $d_i$  is the distance between MS and AP. But, as we mentioned earlier, in a real situation, the intersection of the three circles generates not a single point, but a set of points. The problem is how to choose between those many nodes. We propose a pure geometric method, which is very simple to implement and computational efficient.

The first condition is for the APs not to be on the same axis. This condition is given by the next equation:

$$\frac{x_1 - x_2}{x_3 - x_2} \neq \frac{y_1 - y_2}{y_3 - y_2} \quad (12)$$

Our solution requires making pairs with every two APs, having as a result the next relation:

$$(r_i - r_j)^2 < (x_i - x_j)^2 + (y_i - y_j)^2 < (r_i + r_j)^2 \quad (13)$$

Where  $(x_i, y_i)$  and  $(x_j, y_j)$  are the coordinates

of the two APs. We consider  $r_i$  and  $r_j$  the radiuses of the two circles. The radius is the same with the distance between AP and MS, distance calculated based on the signal strength sensed by the mobile device.

A. If both inequalities in relation (13) are true, this means that we have two points of intersection. The coordinates of these points are given by the following system of equations (14):

$$\begin{cases} (x_M - x_i)^2 + (y_M - y_i)^2 = r_i^2 \\ (x_M - x_j)^2 + (y_M - y_j)^2 = r_j^2 \end{cases} \quad (14)$$

$$\begin{matrix} M_1(x_{ij1}, y_{ij1}) \\ M_2(x_{ij2}, y_{ij2}) \end{matrix} \quad (15)$$

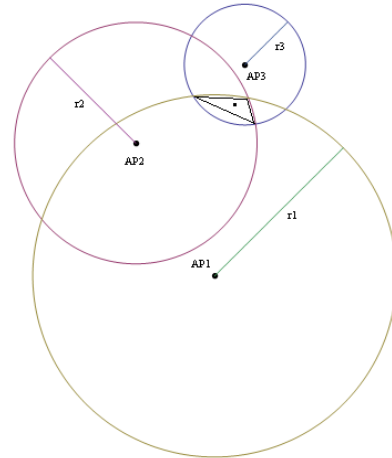


Fig. 5 Intersection points of the three circles

In case each pair of AP generates two points of intersection, it results a total number of six points, as in the Fig. 5.

B. If the right inequality of relation (13) is false, then we have:

$$(x_i - x_j)^2 + (y_i - y_j)^2 \geq (r_i + r_j)^2 \quad (16)$$

This means that the two circles are not intersected. In this case we consider a single point

situated on the axis defined by the centers of the two circles. The coordinates of this point are:

$$M_{ij} \left( \frac{x_i + kx_j}{1+k}, \frac{y_i + ky_j}{1+k} \right) \quad (17)$$

$$k = \frac{r_i}{r_j}$$

C. If the left inequality of relation (13) is not satisfied, then we have:

$$(x_i - x_j)^2 + (y_i - y_j)^2 < (r_i - r_j)^2 \quad (18)$$

This means that one circle is contained by the other one. As in the previous case the point is situated on the axis defined by the centers of the two circles.

$$M_{ij} \left( \frac{x_p + kx_q}{1+k}, \frac{y_p + ky_q}{1+k} \right) \quad (19)$$

$$k = \frac{r_j}{r_i}$$

$$x_p = \frac{r_j}{\sqrt{(x_j - x_i)^2 + (y_j - y_i)^2}} (x_j - x_i) + x_i$$

$$y_p = \frac{r_j}{\sqrt{(x_j - x_i)^2 + (y_j - y_i)^2}} (y_j - y_i) + y_i$$

$$x_q = \frac{r_i}{\sqrt{(x_j - x_i)^2 + (y_j - y_i)^2}} (x_j - x_i) + x_i$$

(20)

$$y_q = \frac{r_i}{\sqrt{(x_j - x_i)^2 + (y_j - y_i)^2}} (y_j - y_i) + y_i$$

The cases B and C generate a single point, but in case A we have two points. In order to choose between them, we apply the next computation. For each of them we make the sum of distances between the node and every other node obtained through one of the three cases: A, B or C.

$$S_1 = \sum_{k=1}^N (x_{ij1} - x_k)^2 + (y_{ij1} - y_k)^2$$

$$S_2 = \sum_{k=1}^N (x_{ij2} - x_k)^2 + (y_{ij2} - y_k)^2 \quad (21)$$

If  $S_1 < S_2$  then we choose node  $M_1$ , else we choose the node  $M_2$ . Thus, we generate a set of points:  $M_{ij}(x_{ij}, y_{ij})$ . The selected points in this way form a polygon and the position of MS will be the point M, approximated with the center of gravity of this polygon. The relations are:

$$x_M = \frac{\sum x_{ij}}{N}$$

$$y_M = \frac{\sum y_{ij}}{N} \quad (22)$$

## Method II

The second method imposes the same general condition [14], namely in the zone where mobile device is acting to be at least three access points. If there are more than three access points a new condition arises: the access points need to create a convex polygon like in figure 6. In this figure we exemplify a case with 4 access points.

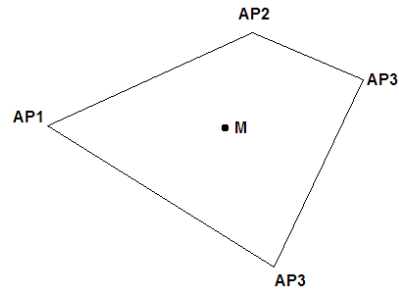


Fig. 6 Access points surrounding the mobile device

If no perturbations interfered along the measuring, at the  $t$  moment, M receive  $P_i$  power from the transmitters  $AP_i$  respectively and distances between M and  $AP_i$  could be calculated with the formula (2).

The algorithm of this method requires grouping every two received RSSI measures therefore we may write:

$$\begin{cases} (x - x_{APi})^2 + (y - y_{APi})^2 = d_i^2 \\ (x - x_{APi+1})^2 + (y - y_{APi+1})^2 = d_{i+1}^2 \end{cases} \quad (23)$$

Solving this system, we will obtain two solutions:

$$(x_{M1}, y_{M1}) \text{ and } (x_{M2}, y_{M2}) \quad (24)$$

From these two solutions we shall choose the point that is at the same side of the line determined by  $AP_i$  and  $AP_{i+1}$ , with another AP (for example  $AP_{i-1}$ ). We can choose any other AP (not  $AP_i$  or  $AP_{i+1}$ ) because they are the vertices of a convex polygon. This point will verify the relation:

$$\left( \frac{x_M - x_i}{x_{i+1} - x_i} - \frac{y_M - y_i}{y_{i+1} - y_i} \right) \left( \frac{x_{i-1} - x_i}{x_{i+1} - x_i} - \frac{y_{i-1} - y_i}{y_{i+1} - y_i} \right) > 0$$

The selected points in this way form a polygon. The position of point M will be approximate by the center of gravity of this polygon.

$$x_M = \frac{(x_1 + x_2 + \dots + x_n)}{n}$$

$$y_M = \frac{(y_1 + y_2 + \dots + y_n)}{n}$$

#### 4 Software framework architecture

The general architecture of the power-aware location framework presented in figure 7 has a layered structure and each layer is divided in several independent modules [14]. The lower layer of the framework application will use the operating system's drivers of different physical components took into account in the optimizing process of energy consumption (the processor, the battery, wireless chipset, main-board chipset, the memory) and location algorithm input measures (WLAN driver). The kernel of the execution framework takes the available measures through the monitoring drivers, calculates the energy consumption of the current running applications and provides a consumption state to the location estimation core. The location algorithm presented before is implemented in the location core module. This module is configured based on application's requirements and power consumption state and its output is provided through a public interface to the application level. Applications using the location framework interface we call location-aware applications.

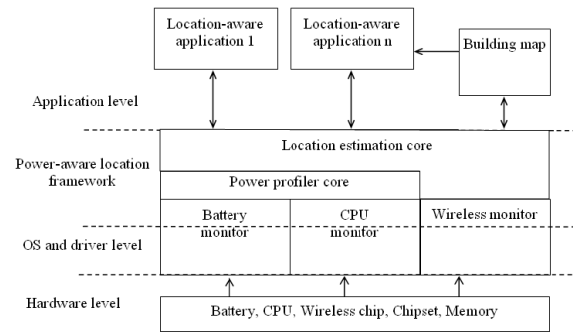


Fig. 7 Positioning framework architecture

The problem in reading the data from the network card on the moving object, was, that it has to be read independent of the model of the wireless network card. More detailed presentation of software architecture and RSSI reading from the software is presented in [14].

### 5 Test bed and test cases experiments

We investigated in our work how trilateration can be used in large rooms positioning and which are the best results some can obtain with this method. Our tests used a large laboratory 13m x 5.5m (Fig. 8) and a number of access points or wireless routers from different providers or types. We set up a number of test cases in order to evaluate our positioning solution, to investigate any problem the solution will face in real life environment and to determine which the main factors that induce these problems are. For every test case we run a number of experiments we based our conclusions.

#### 5.1 Test case 1

In the first test case we investigated how the AP type and device influences the accuracy of positioning algorithm. We used 6 types of APs from two providers: dLink and Linksys (DWL-G700AP, DI-624, DWL-2100AP, WAP55-AG, WAP54-G, and WRT54-GS) and we used also different devices on the same type. We run the testing algorithm a large number of times for different parameters: test duration, sampling times, number of samples averaged for one position computation. The same test was run then a number of times for the same device and the for different AP devices.

We placed a number of access points and we measured the RSSI in different well known positions (Fig. 8). During these test case



experiments we selected a number of “good” AP devices which are well suited to be used in the positioning system and also we calibrated the tests parameters. For every position a 30 minutes capture was saved. During tests were made two readings of RSSI per second and we averaged the last 10 seconds measurements (20 samples) for every position estimation. In the test published by other authors they used smaller amount of times for their tests (e.g. 50 seconds in [1]). We consider that the validation tests should last a larger amount of time because there are many propagation phenomena we should account and for smaller test times we can obtain only a particular result.

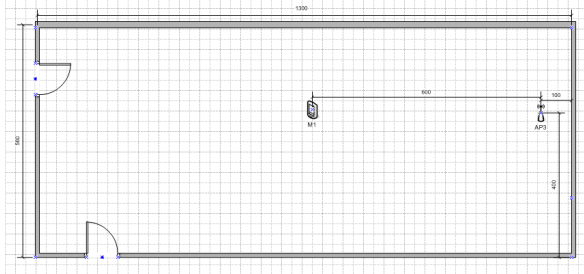


Fig. 8 Test scene and first test case

```

testing_algorithm(
    test_time, sample_time, average_no)
begin
    select_device_params(transm_power)
    start_timer(timer)
    while( timer < test_time )
    begin
        for each ap in surroundings
        begin
            read_rssi(rssi)
            average_rssi(rssi, average_no)
            compute_distance(average_rssi)
            record_data(distance)
        end
        compute_position(position)
        record_data(position)
        sleep(sample_time)
    end
    stop_timer(timer)
end

```

Even if between the access points and the mobile node are no obstacles, the values of RSSI are very oscillating. These variations are caused by a couple of elements of which we can mention the device type and reflections of the signal in an indoor environment. The oscillations of sampled RSSI depend on the AP device therefore we selected a number of good devices. To see if the fluctuations are generated by the devices we conducted a set of measurements using deferent type of devices:

- Linksys WAP55AG - 20mW, 6m, 30min
- Linksys WAP55AG - 25mW, 6m, 30min
- Linksys WAP54G - 20mW, 6m, 30min
- dLink DL624 - 8mW, 6m, 30min
- dLink DWL-G700AP 6mW, 6m, 30min

On good device we selected for the system is presented in Fig. 9 (RSSI variations) and Fig. 10 (distance estimations).

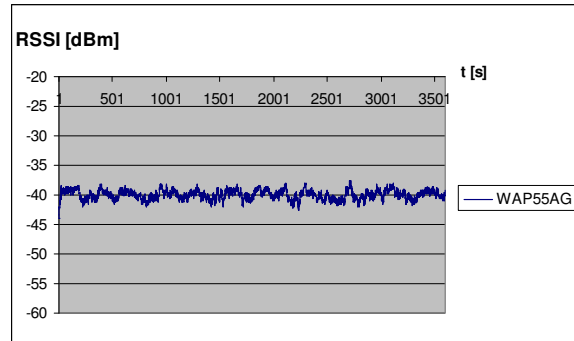


Fig. 9 RSSI for a good AP

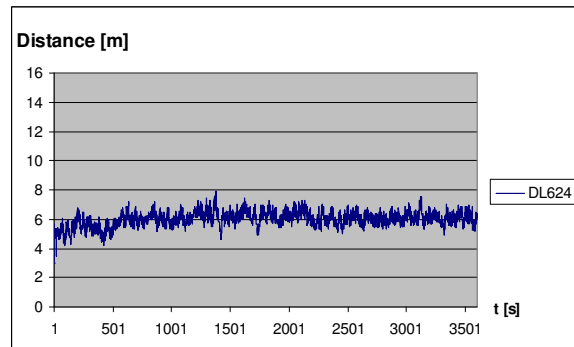
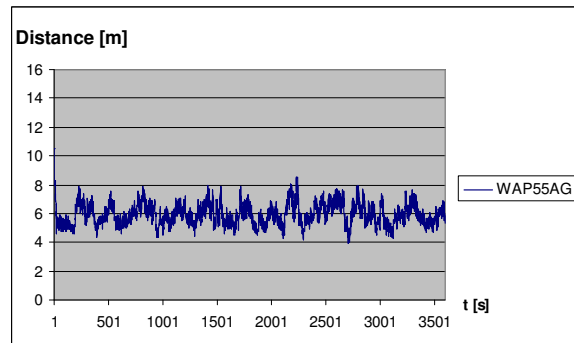


Fig. 10 Distance estimation for two good APs

We can observe that small changes in RSSI expressed in dBm induce large variations in distance estimation. In Fig. 11 we plot the histograms for the distance estimations of DL624 and WAP55AG APs shown in Fig. 10. The distance between AP and target device was 6 meters and we obtained an average error of 3 meters for WAP55AG and standard deviation of 0.75; and average error 2 meters for DL624 with a standard deviation of 0.51.

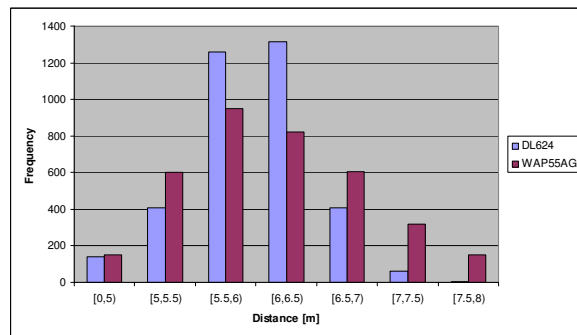


Fig. 11 Distance estimations histogram

One bad example for a device which cannot be employed by a positioning system is presented in Fig. 12 with the average error of 6 meters.

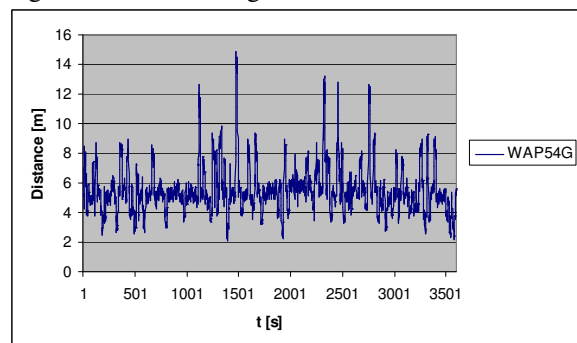


Fig. 12 Distance estimation for a noisy AP

## 5.2 Test case 2

To examine the impact of the distance between the access point and the mobile device over the RSSI we made the following measurements in the testbed described in Fig. 13.

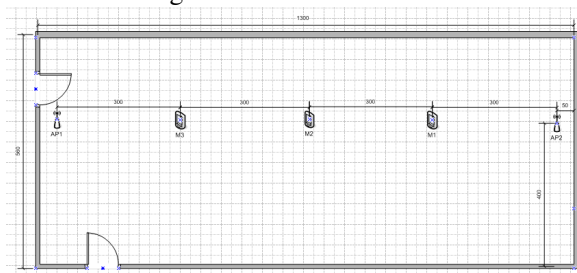


Fig. 13 Test scene for second test case

Test setup:

1. Linksys WAP55AG - 20mW, 9 m, and Dlink DL624 - 8mW, 3 m, 30 minutes
2. Linksys WAP55AG - 20mW, 6 m, and Dlink DL624 - 8mW, 6 m, 30 minutes
3. Linksys WAP55AG - 20mW, 3 m, and Dlink DL624 - 8mW, 9 m, 30 minutes

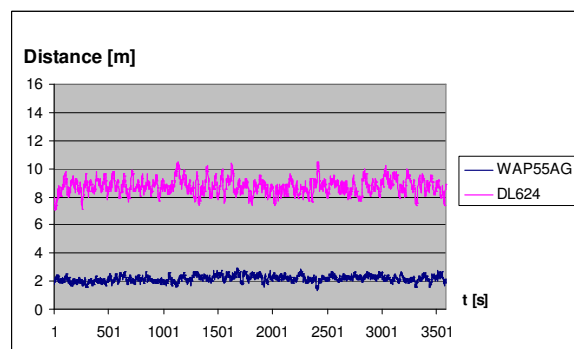
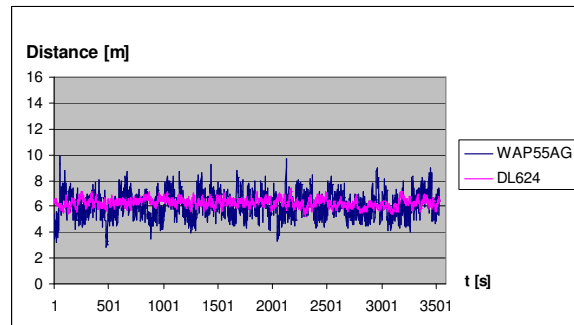
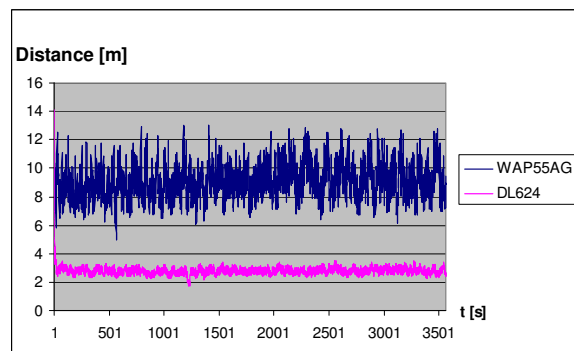


Fig. 14 Estimated distance from one MD to two APs

We observed an increase in measurement standard deviation when the mobile device moves away from the AP.

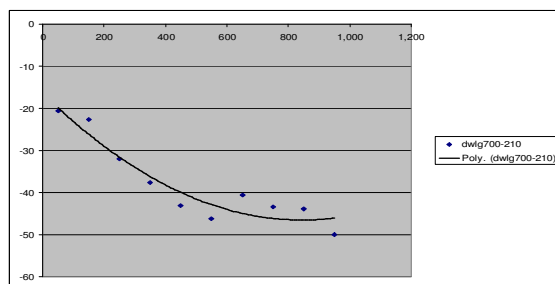


Fig. 15 Relation between RSSI and distance for Linksys WAP55AG

We placed a number of access points and we measured the SS in different well known positions. For simplicity we placed a mobile device between

two APs, from 1 meter to 1 meter. For every position a 30 minutes capture was saved. The relation between the received signal strength and the distance between emitter and receiver for some devices are presented in Fig. 15.

### 5.3 Test case 3

Using three APs the position of a mobile device inside the room can be estimated Fig. 16. The test uses:

- Linksys WAP55AG - 20mW
- Dlink DL624 - 8mW
- Dlink DWL-G700AP - 8mW

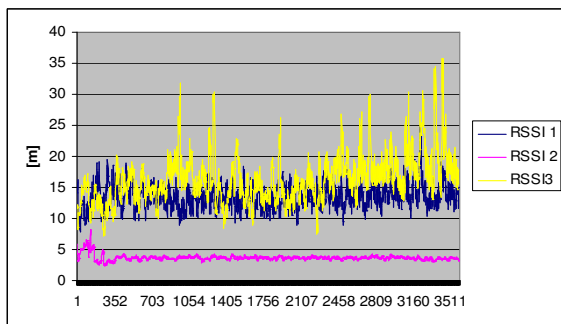


Fig. 16 Position estimation from 3 APs

### 5.4 Test case 4

The tests presented by other authors for their wireless positioning systems were taken without people moving around in the building. We consider that when there are people inside the room they influence the accuracy of the positioning process. We let the system running for one day and we obtained the graphic in Fig. 17.

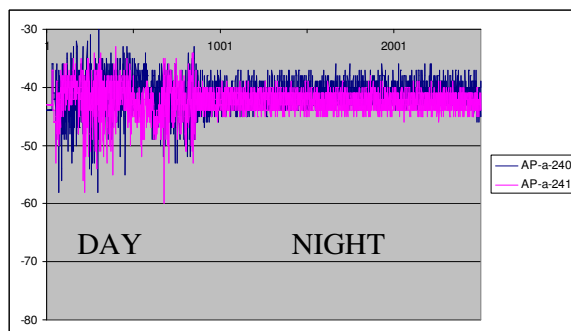


Fig. 17 Day and night positioning accuracy

Differences could be observed in received signal power between the two devices, between day and night and between signal level and signal dispersion. During the day, the room was used by the students

and the presence of people has influence on the RSSI. This could be a problem because the WPS are intended to be used when the users are inside the room. Therefore a WPS should consider the day characteristics of the test when people are present and move in the room.

### 5.5 Test case 5

Running the framework application on the mobile device has influence on the time the battery will discharge. Fig. 6 shows the battery discharging capacity when no applications are executed on a laptop and when the framework application is executed. A minimum consumption difference of 5% was obtained in our tests.

An interesting aspect is that related to the idle state power consumption with WLAN chipset switched off, WLAN chipset set on and WLAN communication show an increase in power consumption as presented in Fig. 18. We can state that wireless communication has three states of power consumption observed at application level: WLAN-OFF power state; WLAN-IDLE power state; WLAN-COMM power state.

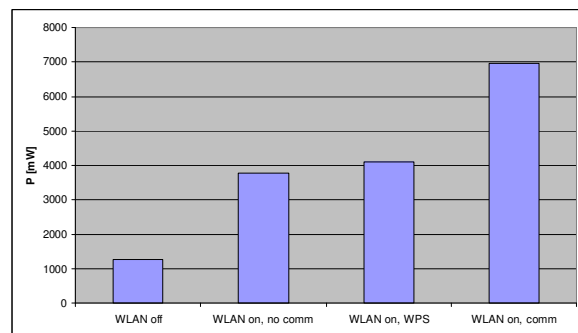


Fig. 18 WPS power consumption

## 6 Conclusions

We presented in this paper an application framework for wireless positioning system. The experimental results with the proposed tests conduct us to the conclusion that our solution is easy to implement, power efficient and suitable for the concept of context-awareness in ubiquitous environments.

In ideal conditions we obtained comparable positioning accuracies with other solutions of around 2-3 meters. In the ideal case we carefully selected the proper APs, we assumed that no users are inside the room to introduce perturbations and the target device was static.

In case we consider real life usage scenarios, there are a lot of aspects which pose serious problems to any wireless positioning system:

- AP device changes: in case one AP in the system is changed (position, device equipment, device type, orientation, etc.), the positioning system should be recalibrated.
- Environment changes: adding, removing or changing objects positions inside the room may influence the accuracy of the positioning system and in some cases need recalibration.
- Mobile device changes: when target device is changing its position, the accuracy of the positioning decrease due to: device orientation, device speed, etc.
- User density changes: when the test scene is used by other people, they influence the propagation model and further the accuracy of the position estimation.

#### ACKNOWLEDGEMENT

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#### References:

- [1] U. Grossmann, C. Rohrig, S. Hakobyan, T. Domin, and M. Dalhaus, "WLAN indoor positioning based on Euclidian distance and interpolation", Proceedings of the 8th Wireless Technologies Kongress, pp. 296-305, Dortmund, Germany, 2006.
- [2] G. Retscher, E. Moser, D. Vredevelde and D. Heberling, "Performance and Accuracy Test of the WLAN Indoor Positioning System ipos", Proc. of the 3<sup>rd</sup> Workshop on Positioning, navigation and Communication (WPNC'06), pp. 7-14, 2006.
- [3] Dylan McGrath, GSM handsets to integrate GPS, EETimes, Dec. 2007.
- [4] H. Lim, L. Kung, J.C. Hou, H. Luo, Zero-Configuration, Robust Indoor Localization: Theory and Experimentation, INFOCOM 2006. 25th IEEE International Conference on Computer Communications. Proceedings, pp. 1-12, 2006.
- [5] M. Broxton, J. Lifton, J. Paradiso, "Localizing a Sensor Network via Collaborative Processing of Global Stimuli", Proceedings of the Second European Workshop on Wireless Sensor Networks, pp. 321-332, 2005.
- [6] A.A. Ali and A.S. Omar, "Time of Arrival Estimation for WLAN Indoor Positioning Systems using Matrix Pencil Super Resolution Algorithm", Proceedings of the 2<sup>nd</sup> Workshop on Positioning, Navigation and Communication, WPNC'05, pp. 11-20, 2005.
- [7] C. Zhang, M.J. Kuhn, M. Brandon, A.E. Fathy, M. Mahfouz, "High Resolution Uwb Indoor Localization System Operating At 8 and 24 GHz Utilizing Time Difference Of Arrival Approach", National Radio Science Meeting, 2006.
- [8] Xinrong Li, Kaveh Pahlavan, "Super-Resolution TOA Estimation With Diversity for Indoor Geolocation," IEEE Transactions on Wireless Communications vol.3 No.1., pp. 224-234, 2004.
- [9] J.C. Chen, K. Yao, R.E. Hudson, "Source localization and beamforming", IEEE Signal Processing Magazine, Vol. 19, No. 2, 2002, pp. 30-39.
- [10] N.B. Priyantha, A. Chakraborty, H. Balakrishnan, "The Cricket Location-Support System", Proceedings of the 6th ACM International Conference on Mobile Computing and Networking (ACM MOBICOM), 2000, pp.32-43.
- [11] B. Li, Y. Wang, H.K. Lee, A.G. Dempster, C. Rizos, "A new method for yielding a database of location fingerprints in WLAN", IEEE Proceedings Communications, Vol. 152, No. 5, 2005, pp. 580-586.
- [12] B. Li, J. Salter, A.G. Dempster, C. Rizos, "Indoor positioning techniques based on Wireless LAN", First IEEE Int. Conf. on Wireless Broadband & Ultra Wideband Communications, 2006.
- [13] U. Grossmann, M. Schauch, S. Hakobyan, "The accuracy of algorithms for WLAN indoor positioning and the standardization of signal reception for different mobile devices", International Journal of Computing, vol. 6, no. 1, pp. 103-109, 2007.
- [14] S. Fuicu, M. Marcu, B. Stratulat, I. stratulat, A. Girban, "An open, low power framework for WLAN indoor positioning system", 13<sup>th</sup> WSEAS CSCC Multiconference, Int. Conf. on Computers, 23-25 July 2009.
- [15] J. Yiming, S. Biaz, S. Pandey, P. Agrawal, "ARIADNE: A Dynamic Indoor Signal Map Construction and Localization System", Proceedings of the 4<sup>th</sup> International Conference on Mobile Systems, Applications and Services, 2006, pp. 151-164.

- [16] P. Bahl, V.N. Padmanabhan, „RADAR: An In-Building RF-Based User Location and Tracking System”, INFOCOM 2000. Nineteenth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE, Vol.2, 2000, pp.775-784.
- [17] A. Karakos, I. Kouris, “Wireless positioning in a university library”, WSEAS Transactions on Circuits and Systems. Vol. 4, no. 7, pp. 455-462. July 2005.
- [18] M. Marcu, D. Tudor, S. Fuicu, S. Copil-Crisan, F. Maticu, M. Micea, “Power Efficiency Study of Multi-threading Applications for Multi-core Mobile Systems”, WSEAS Transactions on Computers, Issue 12, Volume 7, December 2008.
- [19] M. Marcu, M. Vladutiu, H. Moldovan, “Microprocessor Thermal Characterization using Thermal Benchmark Software”, WSEAS TRANSACTIONS on COMPUTERS, Issue 11, Volume 5, ISSN 1109-2750, pp. 2628-2633, November 2006.
- [20] M. Marcu, S. Fuicu, A. Girban, and M. Popa, “Experimental Test Cases for Wireless Positioning System”, IEEE International Conference on "Computer as a Tool", EUROCON 2007, Warsaw, Poland, Sep. 2007, pp. 530-537.
- [21] M. Marcu, S. Fuicu, A. Girban, “Local Wireless Positioning System”, 4th International Symposium on Applied Computational Intelligence and Informatics, 2007. SACI '07, Timisoara, Romania, May. 2007, pp. 171-176.
- [22] M. Marcu, S. Fuicu, A. Girban, “A mathematical model for Wireless LAN indoor positioning system”, The 10<sup>th</sup> International Conference of TENSOR Society on Differential Geometry & Its Applications and Mathematical Foundations of Information Sciences & Its Applications, TENSOR 2008.
- [23] J.C. Chen, K. Yao, R.E. Hudson, “Source localization and beamforming”, IEEE Signal Processing Magazine, Vol. 19, No. 2, 2002, pp. 30-39