Abstract: - 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. 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. In this field there are two main categories of signal strength (SS) based techniques for positioning using WLAN: “trilateration” and “location fingerprint”. We want to propose a method based on some kind of trilateration scheme with a simply and clearly mathematical model. After that we suggest an experimental software framework which includes this scheme. The experimental results show that the proposed solution is quite robust and gives accurate localization results.

Key-Words: - wireless positioning systems, power consumption, energy efficiency, mobile applications

1 Introduction
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 [1]. Hence we can say that we shall face with a pronounced development of the number of applications that run on such devices.

The goal of this article is to describe an open, power-aware, execution framework for an indoor positioning system. The main requirement in developing such a framework was to design a software system with minimum impact on power consumption. The experimental tests presented in section 5 reveal that this target was achieved.

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.

2 Related works
There are three different localization methods that can be used for the localization procedure. These methods are divided into three major categories based on the environment in which the information is spread: indoor, outdoor or mixed.

The localization systems consist of algorithms and methods and are classified based on the signal types [19] (infrared, ultrasound, ultra-wideband, and radio frequency) or based on signal metrics (global location systems -outdoor methods-, cellular location systems -mixed methods- and indoor location systems).

The most popular “global location system” is known as GPS. 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. Depending on the measurements, the indoor systems are also divided into several categories, such as: Distance Measurements (TOA - Time of Arrival presented in [24, 8], TDOA - Time Difference of Arrival presented in [17, 18], RSSI - Received Signal Strength Indicator presented in [19, 20, 14, 15]), Angle Measurements (AOA - Angle of Arrival, DOA -Direction of Arrival [23]) and Fingerprinting (Received Signal Strength (RSS) patterns [21, 22]).

For the distance measurements the most common methods are the one based on computing the distances between nodes using additional equipments for the ultrasonic localization and the one based on measuring the signal strength [5]. The
measurements of AOA, TOA, or TDOA require special hardware at either the infrastructure side or the client side.

Other solutions for the localization are presented in [16, 6, and 7] and are based on the ultrasonic triangulation which requires mounting an ultrasonic transmitter/receiver on each node as well as the necessary circuitry for the signal processing in order to establish the node’s position. The main problem of this solution is that it is not efficient enough because of indoor localization conditions, such as low power signals.

An indoor localization method using a WLAN network is presented in [2], where the probability densities of different areas are computed and the one that represents the best area based on the current measurements is chosen followed by updating the database.

A more peculiar indoor localization system is described in [13], where an efficient positioning algorithm for the localization of the equipments is presented, because of the weak WLAN signal in order to reduce the number of receivers and signal amplifiers.

A network-based localization method is presented in [4], 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 [3], 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.

### 3 Trilateration approach

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 station (MS) 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 station (MS).

The method chosen for obtaining the distance between AP and MS is based on the signal strength (SS) measurement. 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):

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

where:
- \(P_t\) – 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 \(P_t\) power from the transmitter AP\(_i\). The distance between M and AP\(_i\) could be calculated with the formula (2):

$$d_i = \sqrt{\frac{P_t}{P_r} \left( \frac{c}{4\pi f} \right)^2}$$

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.

### 4 Mathematical model

In order to resolve this problem of trilateration we use a geometric method. In the ideal case, the solution is generated by the following system of equations:

\[
M : (x_M - x_1)^2 + (y_M - y_1)^2 = d_1^2
\]

\[
M : (x_M - x_2)^2 + (y_M - y_2)^2 = d_2^2
\]

\[
M : (x_M - x_3)^2 + (y_M - y_3)^2 = d_3^2
\]

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 to resolve 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:

\[
\frac{x_1 - x_2}{x_3 - x_2} \neq \frac{y_1 - y_2}{y_3 - y_2}
\]  

(3)

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

\[
(r_j - r_i)^2 < (x_i - x_j)^2 + (y_i - y_j)^2 < (r_i + r_j)^2
\]  

(4)

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 SS sensed by de MS.

A. If both inequalities in relation (4) are true, this means that we have two points of intersection. The coordinates of these points are given by the following system of equations (5):

\[
\begin{align*}
(x_M - x_j)^2 + (y_M - y_j)^2 &= r_j^2 \\
(x_M - x_i)^2 + (y_M - y_i)^2 &= r_i^2 \\
M_{ij}(x_{ij1}, y_{ij1}) \\
M_{ij}(x_{ij2}, y_{ij2})
\end{align*}
\]

(5)

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

B. If the right inequality of relation (4) is false, then we have:

\[
(x_i - x_j)^2 + (y_i - y_j)^2 \geq (r_i + r_j)^2
\]  

(7)

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:

\[
M_{ij}\left(\frac{x_i + kx_j}{1 + k}, \frac{y_i + ky_j}{1 + k}\right)
\]

(8)

\[
k = \frac{r_i}{r_j}
\]

C. If the left inequality is not satisfied, then we have:

\[
(x_i - x_j)^2 + (y_i - y_j)^2 < (r_i - r_j)^2
\]  

(9)

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.

\[
M_{ij}\left(\frac{x_p + kx_q}{1 + k}, \frac{y_p + ky_q}{1 + k}\right)
\]

(10)

\[
k = \frac{r_j}{r_i}
\]

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

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

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

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

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.

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

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

(11)
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:

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

(12)

5 Software framework

The general architecture of the power-aware location framework presented in figure 2 has a layered structure and each layer is divided in several independent modules. 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.

In order to show how different location environments and using patterns influence the location algorithm of a mobile device at the application level, we started to implement a prototype of the framework. The prototype is written in C++ using MS Visual Studio 2005. The execution framework prototype source code is portable so it could be build and test on different Microsoft Windows platforms: Win32, Window Mobile 5.0 PocketPC and Windows Mobile 5.0 Smartphone.

The framework application is composed from a number of specialized modules (Fig. 2):

- Battery monitor - is a software module running at OS and drivers level, used to achieve real-time on-line power consumption measures from battery device;
- CPU monitor - is a software module used to monitor CPU parameters such as load, temperature, etc.;
- Wireless monitor - is a software module implemented to monitor different parameters of wireless communication: signal power strength (RSSI), bandwidth, data transferred, propagation time, etc.;
- Other types of monitoring modules could also be implemented.

- Power profiler core - the logging and power profiling module extract relevant monitoring data and provide these data to location algorithm level to reduce power consumption.
- Location framework extract relevant wireless monitoring data computes the location of the mobile object and provide this data to application level.
- Location-aware applications are user or system applications which use the estimated location to provide context (locations) dependent services.

The implementation of location core logic can be divided into two parts:

a. Reading the data from the network card placed on the mobile device: access point scanning, radio signal strength reading - wireless monitor;
b. Determining the position based on the signal strengths read, and, based on the reference signals of the access points, determining the position of the object - location estimation core.

The problem in reading the data from the network card on the moving object, was, that it has to be read independent of the type/model of the wireless network card.

Network drivers in Windows NT based operating systems (Windows 2000, Windows XP, Windows 2003) implements the OSI communication stack standard. NIC (Network Interface Cards) drivers implements the communication with a specific network card. NDIS (Network Driver Interface Specification) provides library support for NIC drivers in order to facilitate their development.
Higher levels of NDIS drivers provides a common interface for upper levels and applications when accessing network services.

Another challenge is to read the data, without the support of the drivers of the wireless network card, since the manufacturing companies of the network cards, do not reveal source code regarding the card driver. So the intention was, using another mechanism, for accessing the network card; the only one available is the NDIS driver built within windows, in the network layer of windows. This method provides query access on all network cards installed in the system, on which the queries are run.

First of all, it is required to query all network cards on the machine, which are registered in the windows registry, in the key folder: SOFTWARE\Microsoft\WindowsNT\CurrentVersion\NetworkCards\. After obtaining the name of the network card, which we intend to query, we access the NDIS driver, and query up all the network cards, until we find one that is supporting the 802.11 standard. If a card is found that supports one of the 802.11 standards, it is possible to query all the networks seen by that card (which means all access points seen by the wireless network card).

Using the NDIS driver, we access the BSSID (Basic Service Set Identifier) List of the card. After that, accessing the extended list of the network card we obtain all the networks (all access points seen). A number of new OIDs (Object Identifiers) are required from the IEEE 802.11 NDIS driver to enable the new wireless functionality. These OIDs will be available via Windows Management Instrumentation (WMI) and are required to be supported. We used NDIS OIDs to scan the observable access points and their RSSI: OID_802_11_BSSID_LIST. A structure containing the list of APs in the neighbourhood is returned.

6 Experimental results
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. 4 and Fig. 5.

Fig. 4 Relation between RSSI and distance for Linksys WAP55G

Fig. 5 Relation between RSSI and distance for dLink DWLG700

From these measurements it can be observed that the relation between RSSI and distance are not quite the same for every device.
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. 7. 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.
We finally introduced the some of obtained experimental measurements into the system of equations presented in the mathematical model. We obtained an accuracy of 1-2 m, which is comparable with the other work results.

7 Conclusion
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, therefore we want to explore this concept in our future work.

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