INDOOR LOCATION SENSING OF PEOPLES AND OBJECTS

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Abstract:

Indoor location sensing of people and objects is beginning to find many applications other than goods tracking and security.
Current technologies for location tracking, such as GPS or differential GPS, are not adequate for indoor applications, where the physics of radio propagation rules out the reception of GPS's weak microwave signals.
The goal of this paper is to present a method for positioning and tracking objects (laptops, PDAs) inside an 802.11b WLAN. The positioning system using 802.11b operates by recording and processing signal strength information at multiple base stations positioned to provide overlapping coverage in the area of interest. It combines empirical measurements with signal propagation modelling to determine user location and thereby enable location aware services and applications.
The method consists of two phases: the ***off-line phase****, where the signal strengths received from the WLAN base stations are measured and stored in a database as reference points (in the signal space), building in this way a radio map for the layout of the floor; the* ***on-line phase****, where the algorithm calculates the position of the mobile user, by comparing its actual position (in signal strength space) with all the reference point's positions (also in the signal strength space), provides the best match and display the result on the laptop or a central station screen, in XY coordinates. The location precision in WLAN is up to 2 meters. Note that WLAN 802.11b is not designed for indoor location sensing*

1. Introduction

The modern home and office are equipped with sophisticated computing and communications devices, many of which require significant effort or specialist knowledge to configure and use effectively. While the complexity of such devices will surely increase in the future, it may be possible to make them user-friendlier by transferring some of the configuration tasks to the devices themselves. These computers would be *context-aware*, changing their behaviour based on how and where they were being used.

Several approaches have been proposed for indoor location sensing; such as infrared sensing, radio frequency, ultrasonic, and scene capture analysis. Position-based location systems track objects by reporting their coordinates in a frame of reference. The actual position measurements may be made in many ways. Object locations can be sensed directly, using measurements of fields generated or affected by them, or by contact methods. Also, locations can be deduced from measurements of other physical properties of the object.

Triangulation systems use measurements of the bearings of objects from known, fixed points to find their locations. Similarly, trilateration (or multilateration) schemes find object positions by determining their distances from fixed points.

A lot of research work has been done in the last years in the area of Radio Frequency Identification (RFID) [1], [2], [3], [4], [6]. Such location systems require the user to carry a RF tag so that readers can sense the user presence. RFID technique uses RFID readers, RFID tags and the communication between them. A RF tag is an active or passive integrated circuit that can be detected by a reader that decodes the data pre-encoded in the tag. A read-only RF tag identifies a device in a similar way to barcodes.

The system has extra fixed location reference tags to help location calibration. These tags serve as reference points and replace the readers, which are expensive. The placement of readers and reference tags is very important to the overall accuracy of the system. This approach requires signal strength information from each tag to readers, if it is within the detectable range. However, RFID system does not provide the signal strength of tags directly to readers. Readers only report the power level. It is necessary to do a preliminary measurement to know which power level corresponds to that distance. The power level distribution is dynamic in a complicated indoor environment, so it is necessary to develop an algorithm to reflect the relations of signal strength by power levels. LANDMARC system approach (Location Identification based on Dynamic Active RFID Calibration) [4], [6] employs the idea of having extra fixed location reference tags to help the phase of location calibration. Because of the dynamic power level distribution in a complicated indoor environment, and of the difficulties to accurately compute the physical distance by using power levels directly, the authors developed an algorithm to illustrate the correspondence between signal strengths and power levels. The system uses 4 RF readers along with 32 tags.

The accuracy depends on the placement of reference tags and is about 2 meters [4], but we abandoned this technique because it is not proper to be implemented in our indoor environment and too much hardware infrastructure is needed.

In [5], the authors use a system based on Wireless 802.11b technology, for locating and tracking users inside buildings. RADAR approach [5] operates by recording and processing signal strength information at multiple base stations positioned to provide overlapping coverage in the area of interest, measurement being done by using a standard 802.11 network adapter. It combines empirical measurements, similar with our approach, with signal propagation modeling to determine user location and thereby enable location aware services and applications. RADAR uses signal strength information gathered at multiple receiver locations to *triangulate* the user's coordinates. Triangulation is done using both empirically-determined and theoretically computed signal strength information. The main advantage of the RADAR system is its simplicity and ease of setting it up. Since the system leverages on the signal strength and signal to noise ratio available from the WaveLAN network interface, it requires a small number of base stations (at least three) and uses the same infrastructure that provides general wireless networking in the building.

Ultrasonic multilateration systems ([7], [8]) determine the positions of objects by measuring distances between ultrasound sources and detectors. In some systems, a transmitter is mounted on the object, and several fixed receivers detect its signal. In others, a number of fixed transmitters generate signals that are picked up by a single receiver on the object to be tracked.

For ultrasonic distance measurement on measurements of the time taken for ultrasound to travel between sources and detectors. Knowledge of the speed of ultrasound in air can then be used to calculate the corresponding transmitter-receiver distance.

The distance determination methods are based on knowledge of the speed of ultrasound in air, which is around 340m/s at room temperature. The relatively slow speed of sound (when compared to, say, that of light) has two main effects on the characteristics of ultrasonic multilateration systems.

Since ultrasound does not propagate through walls, signals emitted by a transmitter in a room are contained within that room, allowing simultaneous, independent distance measurements using ultrasound in neighbouring, but distinct spaces.

The range of ultrasonic frequencies that are suitable for use in positioning systems is narrow. The lower margin is around 20kHz, below which the sound may be audible to people with keen hearing, which may then be distracted by those emissions. The upper margin is dictated by the absorption of ultrasound in air, which increases sharply with frequency. For these reasons, ultrasonic multilateration schemes often use frequencies in the range 40 (75) kHz, permitting accurate transmitter-receiver distance measurements at ranges of up to 10m.

All ultrasonic multilateration systems suffer from problems caused by noise interference and reflections. Reflection problems are particularly severe when the trackers are used in cluttered indoor environments. Ultrasonic signals may reflect off surfaces in such a way that they reach the receiver along routes longer than the direct transmitter-receiver distance.

Distance measurements made using a reflected signal will be longer than those made using a direct path signal and could introduce errors into the multilateration calculation.

The ultrasonic positioning system is a very accurate one, with a precision of a few centimetres, but is relative expensive to implement in an office or home environment.

2. The 802.11B Standard Description

As we An 802.11 WLAN is based on a cellular architecture where the system is subdivided into cells. A Base Station (called Access Point - AP) controls each cell (called Basic Service Set - BSS). Most installations can be formed by several cells, where the Access Points are connected through some kind of backbone (called Distribution System - *DS*).

The whole interconnected Wireless LAN, including the different cells, their respective Access Points and the Distribution System, is seen as a single 802 network to the upper layers of the OSI model and is known in the Standard as Extended Service Set - *ESS*. Fig. 1 shows a typical 802.11 LAN diagram.

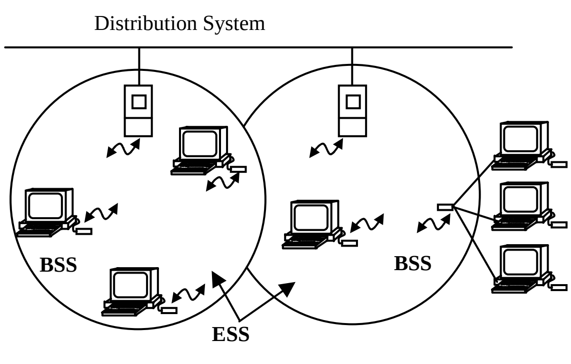


Fig. 1. A typical 802.11b LAN diagram

The 802.11b protocol operates in the unlicensed 2.4GHz ISM band, using DSSS (direct sequence spread-spectrum) transmission. Data is transmitted on BPSK and QPSK constellations. Maximum data rate is about 11 Mbits/s with fallback rates of 5.5, 2 and 1 Mbits/s, depending on distance, noise and other factors. Range can be up to 100m, but this, too, is dependent on the environment. In a protocol view 802.11b only modifies the bottom 2 layers of the 802 models, PHY & MAC, (OSI layers 1: Physical & 2:DataLink). Any LAN application, network operating system, or protocol, including TCP/IP and Novell NetWare, will run on an 802.11 compliant WLAN as easily as they run over Ethernet.

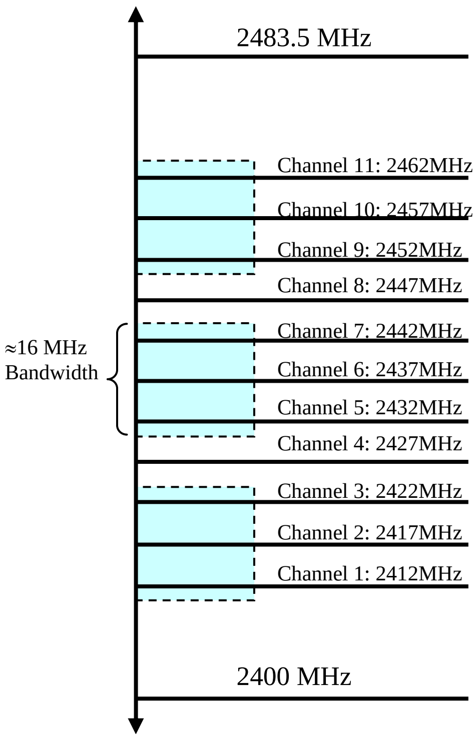


Fig. 2. Channel spacing in 802.11b

The 802.11b standard defines 11 possible channels that may be used. Each channel is defined by its "center frequency". The center frequencies are at distances of 5MHz from each other. Since the high bandwidth (20dB) could give a signal as wide as 16MHz, multiple co-located networks channels have to be spaced out from another (figure 2).

Thus, one 802.11b network could operate at any channel, but 2 co-located networks would have to have enough spacing, say channel 3 and 9, giving a minimum of 18 MHz in between them. Similarly, 3 co-located networks would have to choose from something like channels 1, 5 and 10, to ensure enough spacing. More than 5 co-located channels are not recommended.

In theory, an 802.11b link should have an effective bandwidth of 11Mbps. But due to processing overhead, signaling information, stray interference, etc, the bandwidth is reduced to a lower value. When more devices operating over the same channel are added and all other factors remaining the same, the interference factor increases, and collisions mean retransmission. Thus it can be said that as the number of devices are increased in the same network, effective bandwidth for a particular link drops.

3. Contribution To Location Sensing And Tracking With 802.11B, Using Labwiew Controlled Instruments

In Our experiments regarding location sensing system performances operate by recording and processing signal strength information at three base stations positioned so as to provide overlapping coverage in the area of interest.

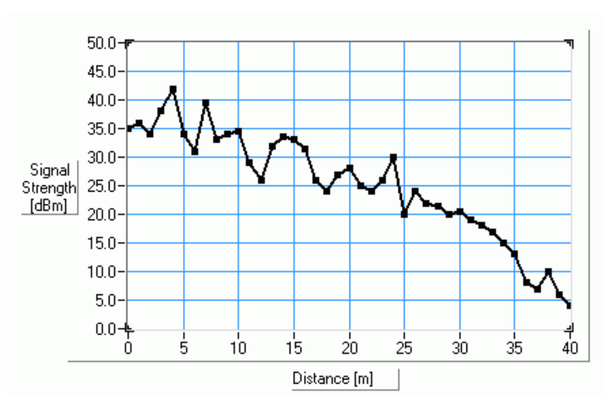


Fig. 3. Signal strength as a function of T-R separation

Fig. 3 illustrates how the signal strength varies with distance between the transmitter and the receiver. The differences in signal strengths between points at similar distances has multiple causes that have an effect on the received signal: the layout of the rooms in the building, the placement of base stations, and the location of the mobile user.

Signals transmitted from two locations at the same distance from the receiver (base station) may be attenuated by different amounts due to the differences in the number and types of obstructions they encounter.

If there are *n* base stations and *m* reference signal strength points on a radio map stored in a computer memory, we define the Range Vector for an unknown position of the mobile user reference point as:

$$u = (u_1, u_2, \dots, u_n), \tag{1}$$

where u_k denotes the signal strength value of the unknown position sensed on base station *k*, $k \in (1,n)$. For the reference signal strength (SS) points, we assume that each one also has its signal strength range vector as:

$$r_i = (r_{i,1}, r_{i,2}, \dots, r_{i,n}), \tag{2}$$

where $i \in (1,m)$. With the known coordinates of all the reference SS points, we are able to physically locate an unknown signal strength point based on the reference cell of the respective unknown point. We use the Euclidean distance in signal strength space. For each individual unknown SS point we have:

$$E_i = \sqrt{\sum_{k=1}^{n} (r_{i,k} - u_k)^2} \tag{3}$$

as the Euclidean distance in signal strength between an unknown SS point and a reference SS point r_i.

For our model the maximum value for i is 42 reference points, and n = 3 base stations.

Let E denotes the location relationship between the reference SS points and this unknown one. There are three key issues that can be examined through the process of locating the unknown SS point.

The first issue is the placement of the reference SS points. Since the unknown SS point is ultimately located in a reference SS point cell, the layout of reference SS points may significantly affect the location accuracy of an algorithm.

The second issue is to determine the number of reference SS points in a reference cell that are used in obtaining the most approximate coordinate of the unknown SS points. This may also be termed as selecting ‘k’ nearest neighbours.

Now, for example we may use the coordinate of the reference SS point with the smallest E value to the tracking SS point as this unknown SS point’s coordinate (k=1), or we can choose 2 nearest SS points (k=2) and the unknown SS point’s coordinates can be simply determined by the arithmetic means of the coordinates of those two nearest SS points as:

$$\begin{aligned} x_{unknown} &= \frac{1}{2}(x_{nearest1} + x_{nearest2}) \\ y_{unknown} &= \frac{1}{2}(y_{nearest1} + y_{nearest2}) \end{aligned} \tag{4}$$

When we are using k nearest reference SS points’ coordinate to locate one unknown SS point, the following equation could be introduced:

$$(x, y) = \frac{1}{k}\sum_{i=1}^{k}(x_{r,i}, y_{r,i}) \qquad (5)$$

However, since the nearest neighbors are not at the same distance from the unknown SS point, we need to assign weight so that the nearest SS point gets more importance than the one far. This becomes the third issue in this approach. Thus, the unknown's coordinate can be obtained as:

$$(x, y) = \sum_{i=1}^{k} w_i (x_{r,i}, y_{r,i}) \qquad (6)$$

Intuitively, this must be done based on the E value of each reference SS point in the cell.

Instead of giving weight to all *k*-nearest neighbours the same weights in averaging, w_i is introduced and it is a function of the E of all *k*-nearest neighbours. The approach of the weight is depending on the E as:

$$w_i = \frac{1}{E_i}\frac{1}{\sum_{i=1}^{k}\frac{1}{E_i}} \qquad (7)$$

In this approach, the reference SS point with the smallest E value has the largest weight.

4. Implementation of the algorithm

Our experiment was carried out on the hallway of Physics' Laboratories from Transilvania University of Brasov. The experimental area has the dimensions of about 18m x 3m and we placed the three base stations (EVO, SMC and IPC1) at the locations indicated in Fig. 4. For diversity, EVO was a PDA, SMC an Access Point and IPC1 a PC equipped with a wireless adapter and running Orinoco Client Manager software. We also used a laptop to collect signal strengths from 42 locations, marked in the figure 4 with green color. This information has been used to construct a radio map and to detect the nearest position of the mobile user, by computing a Euclidean distance (in signal space) and detecting also the value that minimizes the distance.

The system of location tracking is based on two applications: the first software, "WLReceiver" created in Visual C++.NET [9] is dedicated to the popularization of a database (signal strength, investigated stations, orientation) required for creating the digital radio map corresponding to the environment and to the system's configuration. The second software created in the graphical programming language, LabVIEW offered by National Instruments, implements the algorithm of location tracking described in the above paper section. In this application, the three levels of the location tracking algorithm (Fig.4) are implemented:

- The circle marked with the black dashed line represents the location determined only with the help of Euclidean distances minimum.
- The circle drawn with the pink continuous line is based on the calculus of Cartesian coordinates averages of "k" neighbors (rel.5).
- The blue circle represented with a dotted line takes into calculation also the weights for the "k" neighbors (rel. 6 and 7).

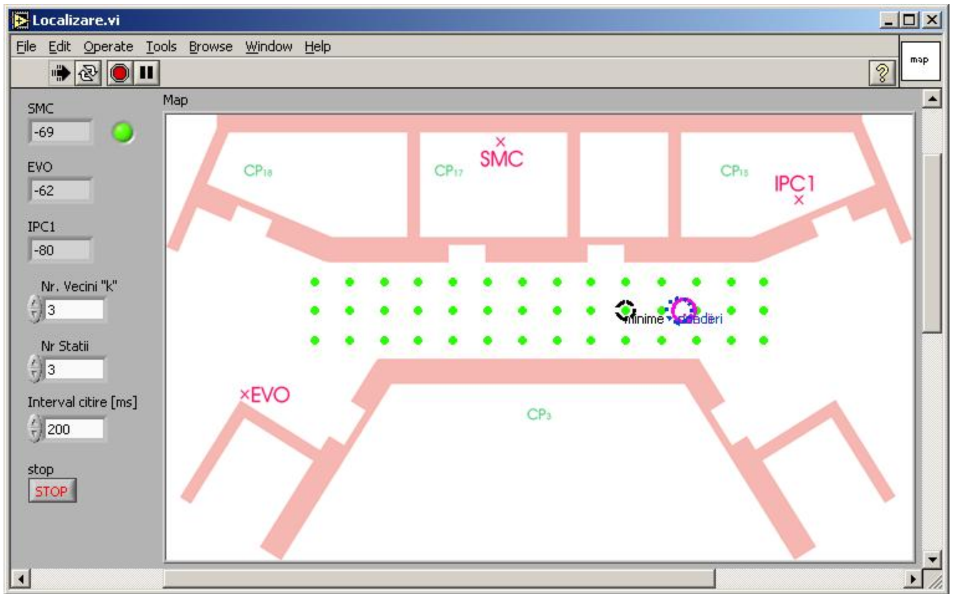


Fig.4 The panel of the Localizare.vi

The structure of the LabVIEW application represented in the Fig.5 is: in the first phase the digital radio map is initialized, reading the signals' values stored in the database (the database has been created in Microsoft SQL populated by WLReceiver) and it is overlapped on the image of the studied environment. Then, the signals' values from different unknown positions for the mobile user are being read. With these known values, the mobile user actual positions will be determined according to the algorithm described above. The positioning error obtained by us was 1.1 – 1.3 m.

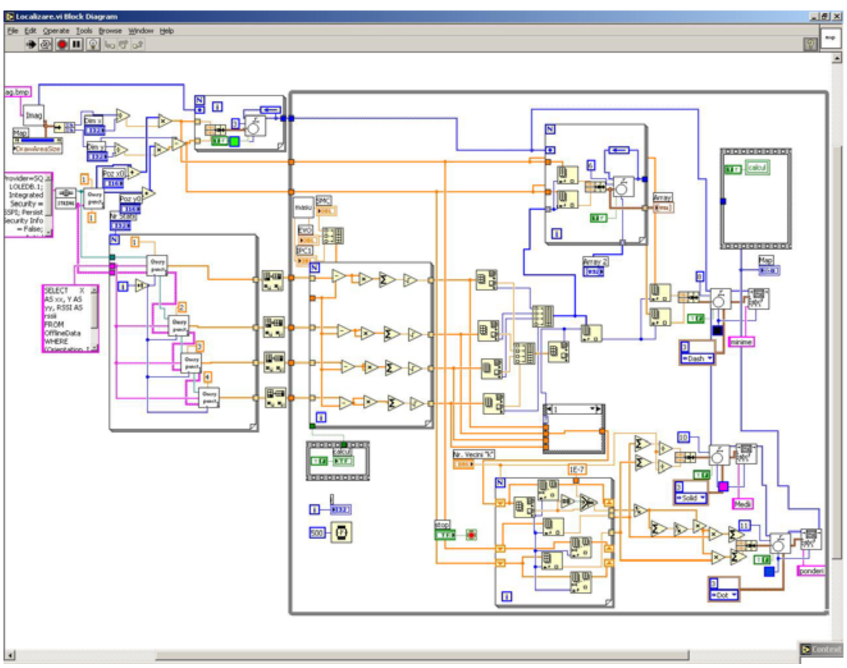
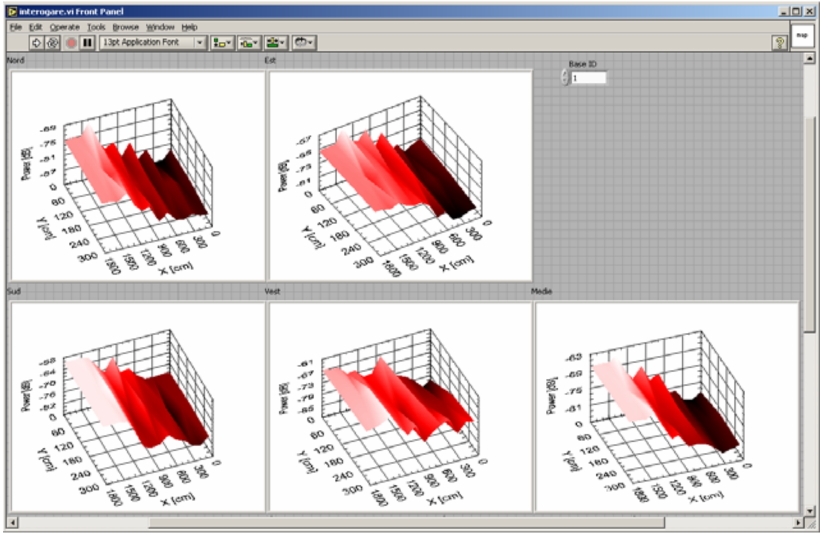
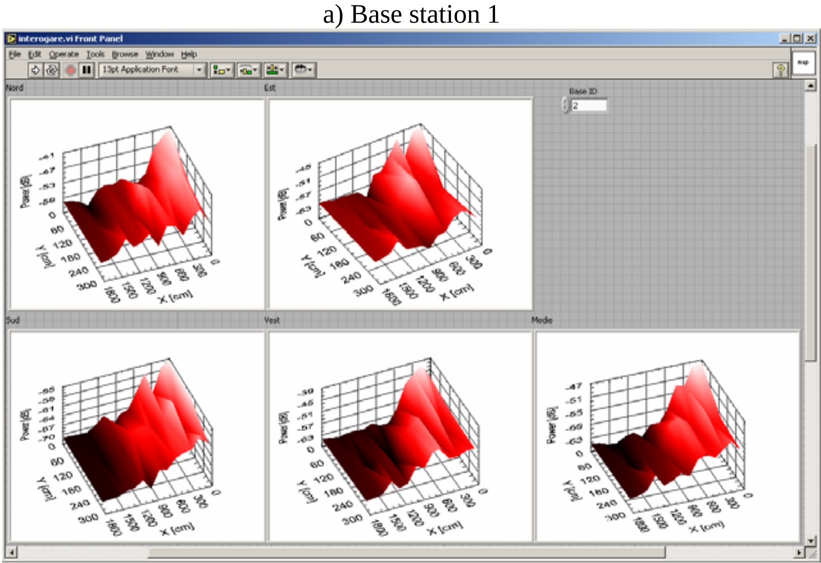


Fig.5 Diagram of the Localizare.vi

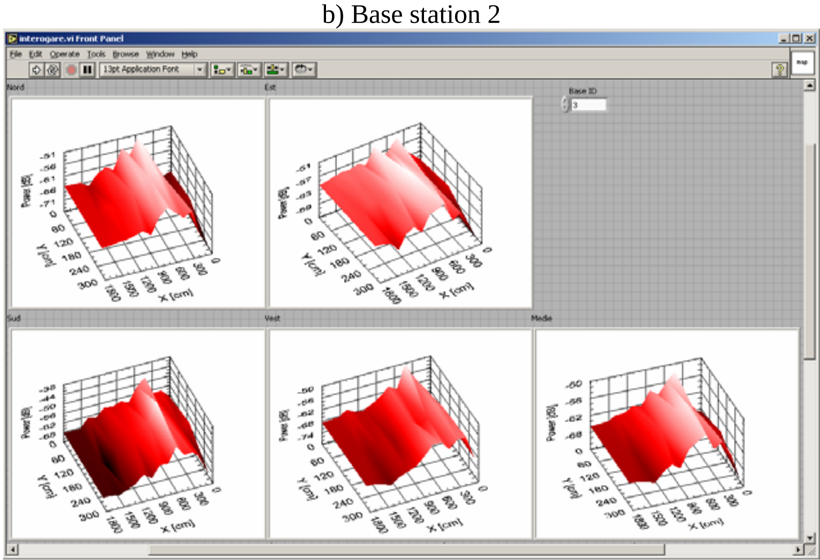
For reading the signals from the base stations, a driver based on wrapi.dll has been used. This driver has been modified in order to be able to concomitant read the signals from three base stations.



a) Base station 1



b) Base station 2



c) Base station 3

Fig.6 The signal’s strength distribution corresponding to the three base stations

In order to be able to visualize the field distribution corresponding to the three base stations in the studied environment, a new application has been created (Fig.6 a, b, c). The signal's strength distribution is represented in 3D coordinates X, Y, Z, where Z denotes the signal strength (dBm).

This application allows the visualization of the signal's distribution on the four directions (North, South, West and East) and their average corresponding to each base station.

5. Conclusions and future research

In the future, passing over the entire application to LabVIEW will be attempted due to its easier way of programming and to the possibility of a more facile information presentation.

It will also be attempted to implement some location tracking criteria for excluding the forbidden areas (walls, furniture, etc.) or including access restrictions map (paths of access).

To eliminate the radio signal strength map, it is necessary to develop a statistical algorithm, based on a radio propagation model, which can determine the location only by considering the signal strength in different points and directly computing the position. Furthermore, we have to implement in LabView some methods to compensate the errors produced due to walls, furniture reflections and human body diffractions.

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