IMPLEMENTING A WIRELESS POSITIONING SYSTEM IN A COMPLEX ARCHITECTURE BUILDING

Anamaria IONAŞCU, PhD. Student Eng., "Technical University of Civil Engineering Bucharest", Faculty of Geodesy, Romania, annamaria_ionascu@yahoo.com

Abstract: *The limitations of GNSS led over time to the development of new positioning technologies able to address the shortcomings for precise positioning in challenging environments. Despite their applicability in many navigation and geodetic purposes, GNSS receivers face problems related to the dependence of accuracy, availability and integrity of signal acquisition on the geometric distribution of available satellites. Indoor navigation does not necessitate high precision, therefore a series of Indoor Positioning Systems based on WLAN, UWB, RADAR, or Bluetooth technologies can be deployed in order to obtain location estimate. The rapid increase of location-aware services, their ease of installation, low costs and good rate mobility for data, transform WLAN networks into very popular means for wireless networking facilities among users and provide centimetre-level accuracy for Indoor positioning purposes.*

Keywords: *GNSS, Indoor environments, WLAN Positioning System, RSSI*

1. Introduction

Location is one of the most important context data utilized in location-aware applications and is given in most cases by coordinates (latitude, longitude, altitude). When dealing with navigation tasks, determining the position of a moving or static object represents a key issue to be solved. In outdoor areas, GNSS satellites provide an effective solution for positioning purposes, offering reliable positioning and navigation services based on high precision. Despite its accuracy and availability, for being a line-of-sight (LOS) system, GNSS is not suitable for navigation and positioning applications in environments where the satellite signals are obstructed.

In urbanized and indoor environments, the line-of-sight towards minimum four satellites condition cannot be accomplished by a GNSS receiver. Satellites are able to register visible, infrared and other wavelengths, therefore the signals transmitted are in the visible spectrum, which means that they will penetrate through clouds, glass, plastic, but they will be easily obstructed by most solid objects such as buildings, mountains, trees etc.

In order to overcome the shortcomings of GNSS positioning in light and deep indoor scenarios, a variety of concepts and systems who make use of Signals of Opportunity have been developed: Pseudolite technology, WLAN Positioning Systems (WPS), Pedestrian Navigation, UBW, RADAR, Bluetooth, Infrared Systems etc. Signals of Opportunity are radio frequency (RF) signals able to ensure location estimate and navigation in areas with obstructed satellite signals,, such as Wireless Local Area Networks signals (WLAN), Global System for Mobile Communication (GSM, UMTS), analogue/digital television-TV, digital/analogue audio.

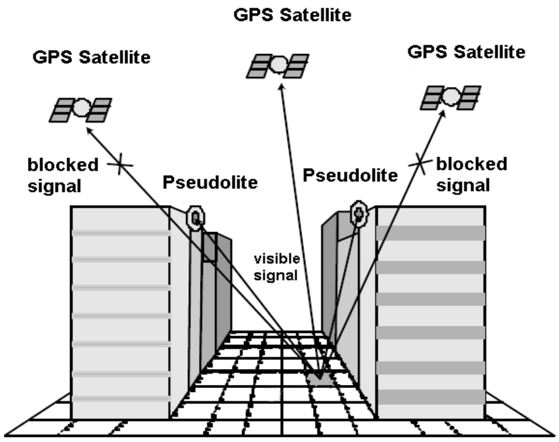


Fig. 1. Areas with obstructed satellite signals

While indoor environments are limited to the size of a room, a building or a tunnel, positioning in outdoor areas requires regional or global coverage, hence an adaptation of GNSS systems to indoor positioning contexts is too expensive and hard to deploy.

The rapid development of 802.11 networks together with new mobile devices (MD) and services compatible with 802.11 set of standards (Wi-Fi, Bluetooth etc.) transform the WLAN technology into very popular means for indoor positioning purposes. Due to the fact that nowadays most buildings such as hospitals, universities, offices buildings, private homes etc. have an already implemented Wi-Fi infrastructure, a WLAN Positioning System can be deployed with minimal effort and good cost-effective ratio in these areas.

Not all positioning and navigation tasks necessitate geodetic, millimetre-level precision. There are many applications able to ensure various services depending on the area of the building in which the mobile device resides. These kind of applications depend exclusively on the topology of that particular environment/building etc. and does not necessitate accurate X, Y, Z coordinates in a 3D coordinate frame. Previous studies and experiments have shown that a WLAN Positioning System can provide meter-level accuracy indoors [4]. There are life situations when it is important to know in which room the user who is holding a mobile device equipped with WLAN technology is located, for instance the position of a friend on the stadium at the Olympic Games or the position of a doctor inside a hospital with a precision of a few meters.

2. System requirements for WLAN Positioning

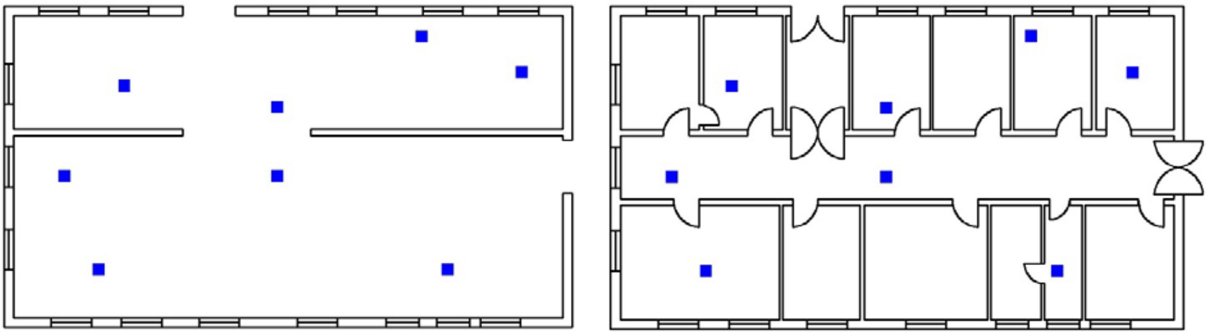
WLAN primary purpose is to ensure local wireless access to fixed network configurations. Since a large number of WLAN Positioning Systems have been proposed and developed, several test plan requirements should be taken into account in order to be able to support such a positioning system. Thus, the system must be able to operate over many wireless technologies (WLAN, Bluetooth, UMTS, GSM, etc.). It should also be able to reflect an up-to-date knowledge of the position and to tolerate a certain amount of interferences.

In order to accomplish these tasks, the following parameters must be specified: latency; update rate; synchronicity and timing; accuracy and confidence level [6]. Latency represents the time between the request for location of a mobile device and the time it takes to respond. At the time when the position is determined, its location may be precise and up-to-date, but in the case when the response time is too long, the location of the device may be inaccurate. The update rate represents the frequency of position determination and distribution and can be performed on request or periodically. The update rate varies between different applications (e.g. tracking requirements, calculations without interruption, updating information). Synchronicity and timing: all distance or Received Signal Strength Indicator (RSSI) measurements must be synchronous over the entire system, in order to avoid errors in the position estimation (e.g. the AP is moved from its initial position). Accuracy and confidence level are very important demands for implementing a WLAN Positioning System, because they relate to outcome in a geodetic network positioning technology.

3. The impact of building architecture and Access Points placement on mobile/static localization

The best configuration which provides a small positioning error can be determined by studying both influence of the WLAN configuration of APs on the precision of a WLAN Positioning System and how to design these systems, in terms of building architecture and what impacts the design, namely the placement of Access Points in the test bed. The radio propagation characteristics must be considered, along with the spacing of the grid of location fingerprints. A fingerprint represents a signal pattern recorded at a specific RP, and they can yield a reference position or location estimate.

Experiments conducted on same surfaces test beds have shown that a WLAN Positioning System is a probabilistic location estimate system able to perform accurate localization and to track stationary and mobile devices [1]. According to tests, if the APs are placed in symmetric positions over the experimental test bed in a simple environment, distributed in such a manner that the Received Signal Strength Indicator is high, it is likely to be the most appropriate way to reduce the location error. On the other hand, due to the various obstacles spread over a complex environment (walls, furniture, doors, etc), the stationary mobile device can be located more accurately. The tracking performances in this case decrease due to the cumulated errors in the previous locations of the mobile device.



a). Simple Environment b). Complex Environment

Fig. 2 – Building layout

In case of a simple environment, a building with few obstacles, the number of APs together with their ideal placement must be considered. The purpose is to understand how the number of APs placed with respect to the topology of the building influences the positioning error. As seen above, few obstacles lead to a complex environment for the signal propagation, therefore a WLAN Positioning System which is composed of less than four APs cannot ensure good coverage for accurate localization. Previous knowledge of RPs locations is a decisive parameter in terms of tracking, which may influence the positioning error.

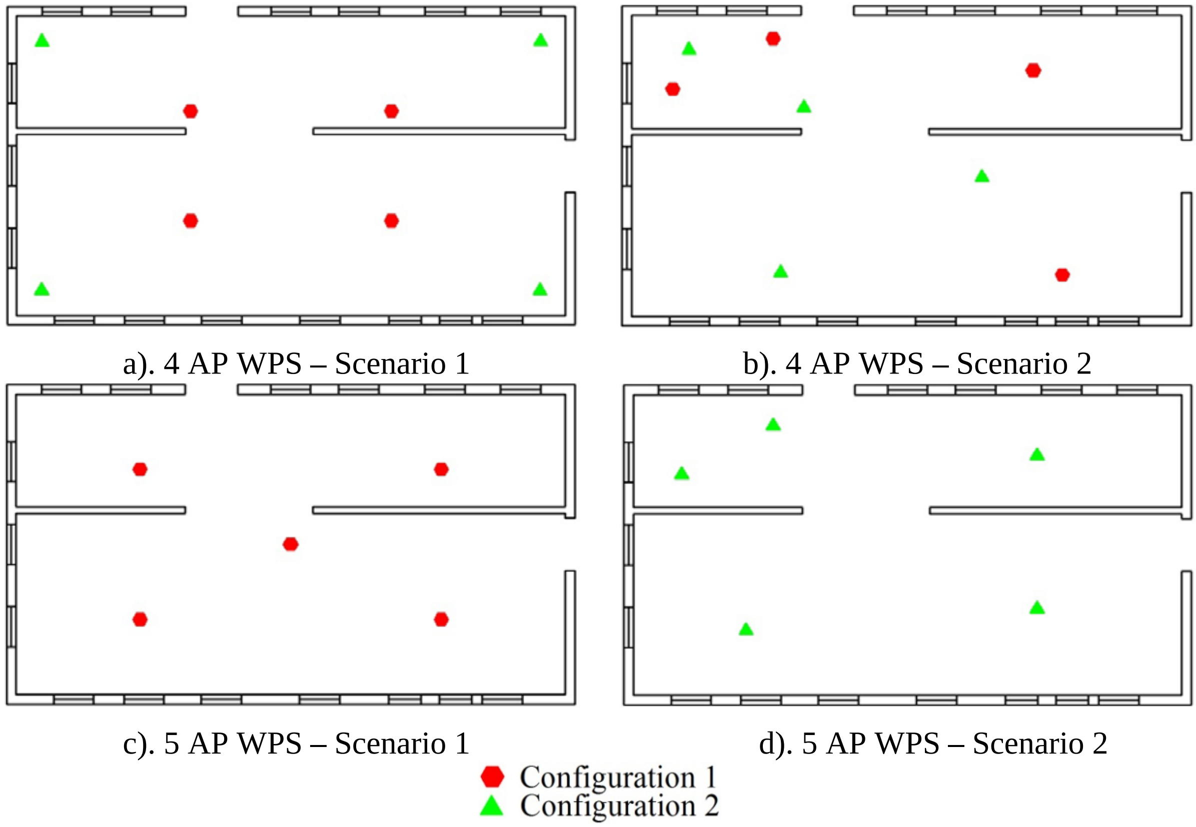
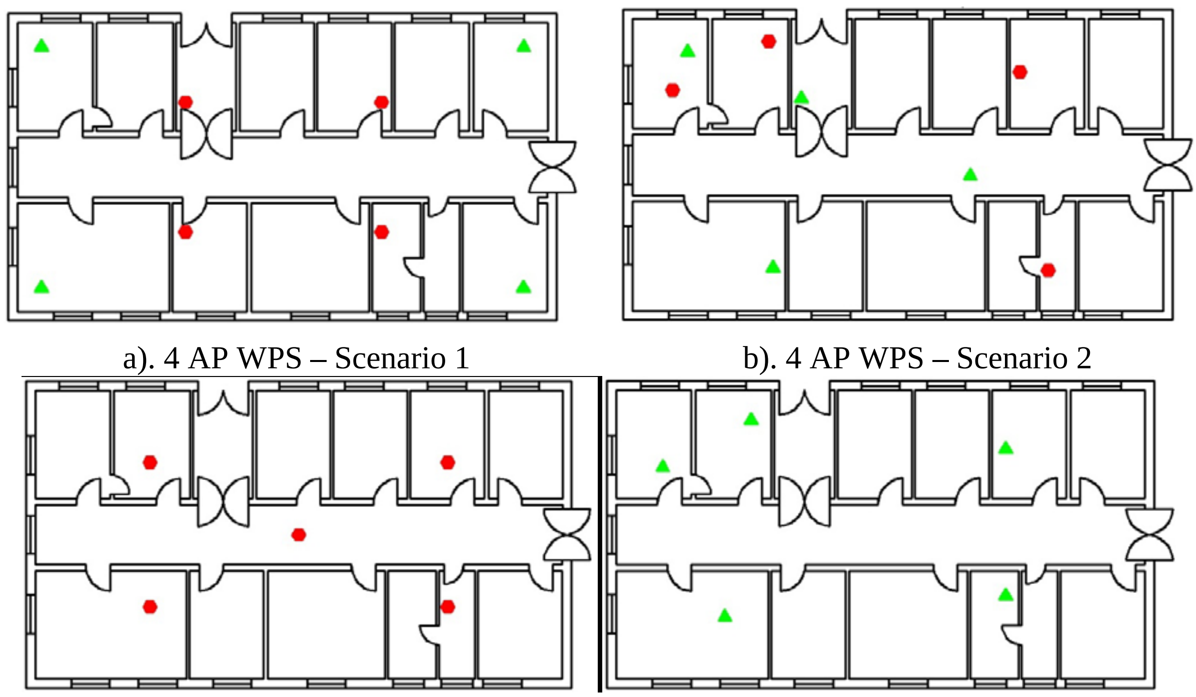


Fig. 3 – Simple Environment: 4 and 5 AP WLAN Configurations

In Fig. 3, a simple architecture building is presented. The first scenario deploys a WLAN Positioning System, with 4 APs symmetrically placed. In the first configuration the APs are placed in the middle of the building (Fig. 3–a). - Configuration 1), and in the second configuration the APs are placed in the corners of the building (Fig. 3–a). - Configuration 2). The same 4 APs scenario is repeated but with a scattered placement of the APs. Experiments conducted in this manner have shown that the average power in the Reference Points deployed in symmetrical placement is lower than in unsymmetrical placement.

Therefore, in a simple environment, with few obstacles, the location estimation precision for tracking is better than for stationary mobile device, with the advantage of previous knowledge of the building layout and previous positions of the mobile device. The most accurate location estimate is obtained with four APs for a stationary mobile device and tracking, in particular, when the APs are distributed symmetrically over the experimental test bed [1]. Adding a new AP does not improves significantly the accuracy in some areas, but improves it globally (Fig.3–c)., d).). Moreover, the central position of the AP generates more perturbation than improvement to the system.



a). 4 AP WPS – Scenario 1 b). 4 AP WPS – Scenario 2

c). 5 AP WPS – Scenario 1 b). 5 AP WPS – Scenario 2

Fig. 4 – Complex Environment: 4 and 5 AP WLAN Configurations

In case of a regular building, more complex, which is a an example of a office building having the same experimental surface test bed as the simple building above, the influence of obstacles on the location estimate error must be considered. Due to high amount of obstacles in a complex environment, such as walls, furniture, moving people, open/closed doors, the RSSI is considerable attenuated.

In Fig. 4 a complex building is presented. The first scenario deploys a WLAN Positioning System, with 4 APs symmetrically placed. In the first configuration the APs are placed in the middle of the building (Fig. 4–a). Configuration - 1), and in the second configuration the APs are placed in the corners of the building (Fig. 4–a). Configuration - 2). The same four APs scenario is repeated but with a scattered placement of the APs. In this particular case, the accuracy of location estimate for a stationary mobile device is always better due to the fact that the obstacles have positive effects on the signal propagation, which make RSSI vectors more diverse. Tracking in a complex environment does not perform very well, because it is based on previous knowledge of the building layout and previous positions of the mobile device, therefore the errors will accumulate at each previous location.

The positioning error of a stationary device decreases while the average signal power increases. The RSSI is higher when the RP is closer to the AP.

4. Study case for implementing a WLAN Positioning System

The WLAN Positioning System measurements have been performed in one of the Institute for Space Applications and Space Technologies buildings, University of the Federal Armed Forces Munich, Germany. The architecture of the building is complex, with different room and corridor types, and obstacles. Due to the fact that the localization system depends on the electromagnetic characteristics of the environment which can suddenly under the influence of several factors (people motion, open/closed doors), the experimental test bed chosen will provide different radio propagation effects alongside with unique fingerprints.

The following steps must be accomplished when a feasible WLAN Positioning System is implemented:

- Data collection – offline phase (building a database of RP identification name and their correspondent RSSI values for each AP, together with time stamps, when needed);
- Location estimate – online phase;
- Position visualization.

The mobile device used for performing WLAN measurements is an MSI PR210 notebook with the following specifications:

- AMD Turion®64 X2 Mobile Technology TL-50 1.60 GHz Processor;
- 2 GB RAM;
- 1xHDD 150 GB;

The notebook has been equipped with a TP Link TL-WN821N USB Wireless Adapter compatible with IEEE 802.11n, IEEE 802.11g, and IEEE 802.11b standards.

The devices specifications are those reported by their developers.

The software used for collecting RSSI samples is inSSIDer, and for the post-processing phase, MATLAB R2011b.

The fingerprints are consisted of RSSI measurements. RSSI is provided by many wireless devices of different technologies and indicates the level of strength achieved by the signal observed by the receptor. The location estimate is achieved by means of measuring RSSIs transmitted by the APs existing in the system in each RP which position must be determined, and comparing these RSSIs with the radio map or database of previous recorded fingerprints.

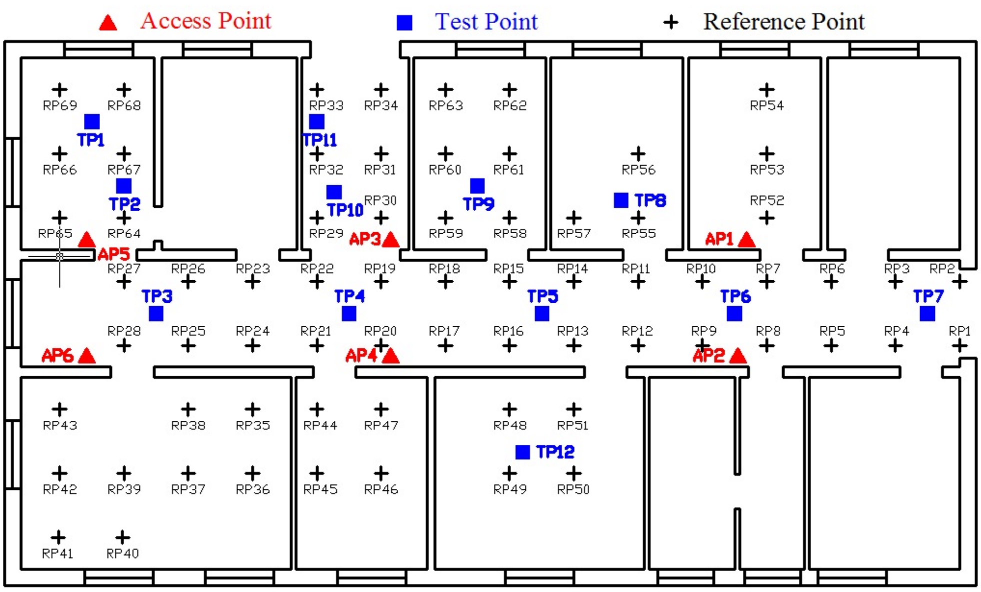


Fig. 5 – Experimental test bed

In the offline phase, a database of location fingerprints is built using measurements of the RSSIs placed in different locations in the building [3]. In order to generate the database, a local frame of reference points (RP) is built. The RPs are selected with respect to the environment obstacles (furniture, doors, walls etc.). The next step is to locate a mobile user (MU) at each RP, so that the signal strengths of all the WLAN APs are measured and the characteristic feature of each RP is determined and recorded in the database. The whole process is repeated until all RPs are visited.

In the positioning phase, the mobile user measures the RSSI at a place where it requires its position and the measurement is compared with the data collected during the offline phase from the database using an appropriate interpolation algorithm. The result is the most likely position of the MU [3].

The Nearest Neighbour algorithm relies on the signal distance between the measured RSSI at specific test points (TPs) which positions must be determined, and the RSSI observed during the training phase. The Nearest Neighbour is the point with the shortest signal distance [5]. The signal distance between the measured SS vector [s1 s2 … sn] and the SS vector in the data base [S1 S2 … Sn] is computed and the generalized distance between the vectors is given by:

$$L_q = \left(\sum_{i=1}^{n} |s_i - S_i|^q \right)^{\frac{1}{q}} \tag{1}$$

$D = \{d_1, d_2, d_3, ..., d_m\}$,

m – number of pattern of RSSI in the database,

q – number of APs

$d_i = \{s_1, s_2, ..., s_n\}$, where n – number of AP, d_i – pattern of RSSI for all APs

S – observed signal strength pattern (RSSI)

$S = \{S_1, S_2, ..., S_n\}$, S_i – observed signal strength from AP_i

L1 – Manhattan distance.

The RPs can be located in fixed geographic locations, such as waypoints (e.g. doors), they can be attached to static objects, or they can be even used as a part of the WLAN Positioning System infrastructure (an AP can act as a RP) [2].

After processing the measurements, it was concluded that although the RSSIs have an constant behaviour in time with only ±5 dB variations, it is still affected by the multipath effect, as seen in Fig. 7. An offset of +10dB is caused by the reflection and refraction from water bodies and surrounding objects.

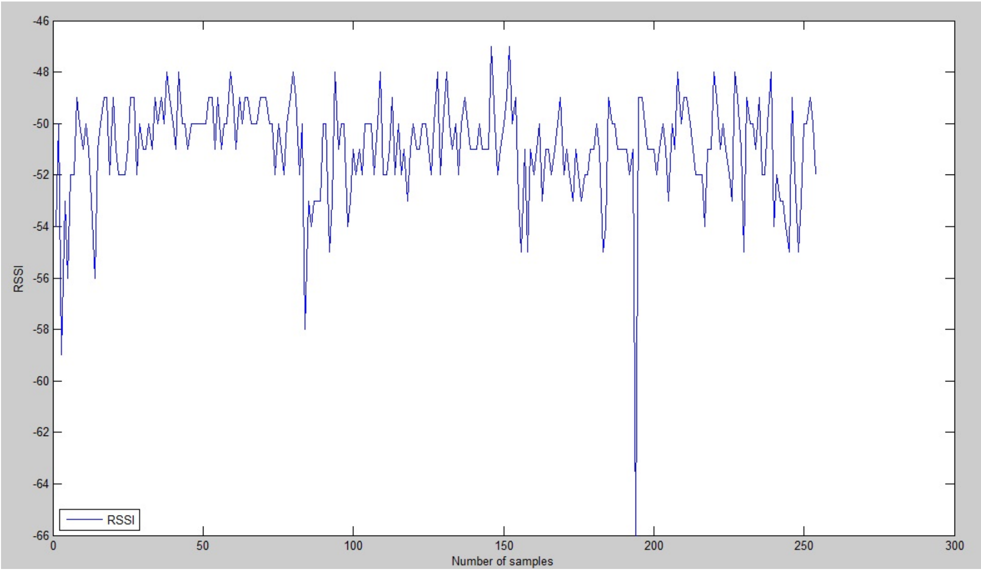


Fig. 6 – Received Signal Strength Indicator samples recorded from one Access Point

Measurements were conducted in each RP for a fixed period of time, with a given orientation, on North, East, South and West (Fig. 8). The distribution of the RSSI is non-Gaussian and varies at the same location or at different locations when the orientation of the antenna changes. Therefore, more measurements must be conducted in order to generate the database, and this increases the duration of the training phase in location fingerprinting. The database size and the computational load are also increased. The rotation North-East-South-West is respected during all measurements. This way, the variations of position of the user towards the mobile device antenna which can affect the signal propagation are implemented in the system. The MD performed a WLAN scan of each AP each second and the insider software collected the RSSI data and its corresponding time stamp in a log file.

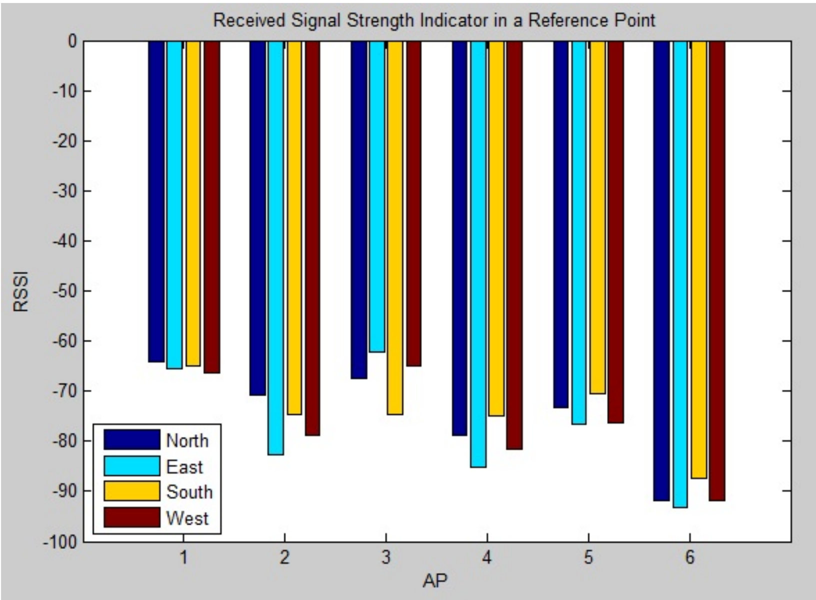


Fig. 7 – Received Signal Strength Indicator samples measured in one Reference Point on different headings

The location estimate following the post-processing stage was obtained with high precision, ranging from 56.57 cm to 106.06 cm.

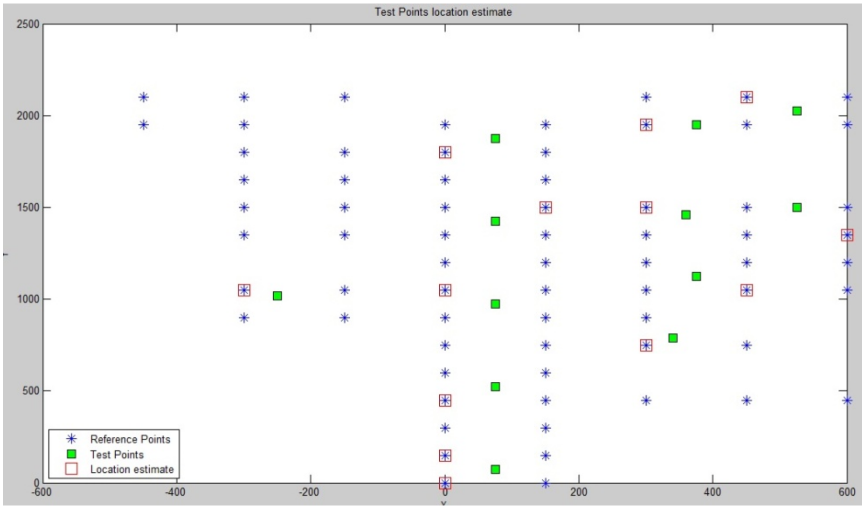


Fig. 8 – Radio map of fingerprints

5. Conclusions

WLAN can be used not also for delivering high speed internet, but also as an accurate Indoor positioning system. One reason for developing a WLAN Positioning System is that the system ensures enough positioning accuracy to be useful for a wide range of applications. Another reason for implementing WLAN Positioning Systems is that WLAN equipped devices can be used in two modes, for data communication and for measuring the Received Signal Strength Indicator from all Access Points situated in close proximity.

The environment which is to be set up as an experimental test bed in order to prove the performance of an Indoor positioning technique must be carefully selected. The environment, for example a building, must have a complex architecture, with different room types and obstacles (e.g. corridors, furniture, doors), in order to obtain different radio propagation effects. Therefore, the fingerprints are more unique. The dimensions of the rooms, corridors etc. should be large enough so that the precision of the positioning system could be tested. The placement and number of APs should be previously established so that it will provide optimal signal coverage for RSSI measurements.

Building a radio map of RSSI is mandatory. To ensure an accurate location estimate of the mobile device, the spacing between two adjacent RPs, namely the granularity must be small. When the RPs are gridded, close to a uniform distribution, and the granularity decreases, i.e. the number of RPs increases, the position can be estimated with higher precision.

6. References

1. *Baala, O., Zheng, Y., Caminada, A. : The Impact of AP Placement in WLAN-Based Indoor Positioning System. Eighth International Conference on Networks, 2009. ICN '09, pp. 12-17, Gosier, Guadeloupe 1-6 March 2009*
2. *Bernardos, A.M., Casar, J. R., Tarrio, P.: Real time calibration for RSS indoor*

positioning systems. 2010 International Conference on Indoor Positioning and Indoor Navigation (IPIN), pp. 1-7, Zurich, Switzerland, 15-17 Sept. 2010

3. *Ionaşcu, A.: Indoor Positioning and Navigation in Areas with Obstructed Satellite Signals. Proceedings of the Scientific Journal of the Technical University of Civil Engineering - Mathematical Modelling in Civil Engineering No. 4 December 2011, ISSN 2069-1793; ISBN 978-973-100-193-7*
4. *Leppäkoski, H., Tikkinen, S., Perttula, A., Takala, J.: Comparison of Indoor Positioning Algorithms Using WLAN Fingerprint. Proceedings of ENC-GNSS 2009, Naples, Italy, 2009*
5. *Li, B., Salter, J., Dempster, A. G., Rizos, C. – Indoor Positioning Techniques Based on Wirelss LAN. First Ieee International Conference On Wireless LAN Broadband And Ultra Wideband Communications, Sydney, Australia 2006*
6. *Peng, B., Kemp, A.H., Brodin, G.: SIP for Wireless Positioning: System and Architecture. Joint IST Workshop on Mobile Future, 2006 and the Symposium on Trends in Communications. SympoTIC '06, pp. 32-25, 24-27, Bratislava, June 2006*