Proceedings of
IEEE International Conference on
Multisensor Fusion and Integration for Intelligent Systems
Seoul, Korea, August 20 - 22, 2008

A Fusion Method Based on Bluetooth and WLAN Technologies for Indoor Location

S. Aparicio, J. Pérez, A. M. Bernardos, and J. R. Casar

***Abstract*—This paper proposes a method for merging Bluetooth and WLAN technologies to face the problem of indoor positioning. Firstly, using Bluetooth measurements the zone where the target object is located is enclosed. Afterwards, processing WiFi measurements the RSS readings are compared only against the fingerprints of the points within the previously determined zone for the precise determination of the object position. In a recent work, we approached this problem by constructing simulated Bluetooth and WLAN maps and assuming that Bluetooth measurements determine precisely the zone where the object is located. Here we present a new algorithm to cope with erroneous identification of the preselected region. The performance of this method has been tested experimentally and the comparison between the localization results obtained using both technologies and using only WiFi is presented.**

I. Introduction

Wireless technologies such as Bluetooth, WLAN (WiFi) or GPS have become world-wide known over the last few years. The proliferation of these technologies, concurrently with the mobile computing devices in which they are embedded, has triggered an increasing interest in context-aware systems and services. Several examples and a full taxonomy of these Location Based Services (LBS) are depicted in [1].

In this framework, indoor location methods come up as a key issue to be addressed. GPS-based systems offer good performances and are widely spread in outdoors environments. However, when the target is located indoors, GPS does not provide an acceptable accuracy due to its Line of Sight (LOS) dependent infrastructure. In recent years, indoor positioning has been studied by many researchers using different technologies. Most of them are developed based on a single technology.

The aim of this paper is to present an indoor location system that takes advantage of fusing Received Signal Strength (RSS) data gathered from multiple wireless technologies. Our goal is to develop a cost-effective system using easily accessible wireless devices. Today it is not uncommon for an average user to carry a mobile phone or a PDA with some of the technologies mentioned above. Several approaches have been made with RF [2], ultrasound [3] or RFID [4]; in this work we have selected IEEE 802.11 wireless LAN (WiFi) and Bluetooth. We will focus our efforts on emphasizing how the combination of multiple technologies improves the reliability of the location measurements with respect to a single one.

This paper is organized as follows. Section II reviews some existing methods for location estimation using a single technology or by means of fusing data from multiple sources. In section III we analyze the features of Bluetooth and WLAN in location systems. In section IV we introduce the algorithm to fuse data from both sources based on Receive Signal Strength in WLAN and Cell Identification in Bluetooth. This algorithm works well in a simulated environment if it is assumed that Bluetooth measurements determine precisely the zone where the object is located. However, in a real layout, many factors affect the computation of that zone, and this may lead to the selection of a zone where the target object is not located. To overcome that problem, an enhanced algorithm is introduced in section V. Section VI gathers some real experiments. The comparison between the localization results of a real target object using the fusion of both technologies and using only WiFi is presented. Finally, section VII contains the conclusions and draws some guidelines for future research.

II. Background

There is a large amount of literature focused on indoor positioning systems using wireless technologies. In most of them, location estimation is addressed by handling a single data source. For example, the RADAR system [2] bases its position calculations on triangulation on RF Received Signal Strength (RSS); there are also systems based on ultrasound such as Active Bat [3] and Cricket [5]; Active Badge [6] uses Infrared, RFID is the key technology in LANDMARC [4] and SpotON [7], while Bluetooth is the foundation of ATLANTIS [8] and other projects [9], [10], [11].

Many other initiatives have also taken advantage of fusing multiple technologies. WLAN and sensors are used in [12] to improve location accuracy. A system based on RFID, WiFi and Vision is described in [13]. In [14] indoor location estimation based on Bluetooth and WLAN is presented. Our work differs from other approaches in the way we accomplish the location calculations using Bluetooth. Most of the previous methods use RSSI and Link Quality information from Bluetooth devices. As we will describe later, our system is based on inquiry reports that detect whether the target device is on its zone or not

Manuscript received February 29, 2008. This work was supported in part by the Government of Madrid under grant S-0505/TIC-0255 (MADRINET) and the Spanish Ministry of Education and Science under grant TSI2005-07344 (COLOCAME).

S. Aparicio is with the ETSI Telecomunicación, Universidad Politécnica de Madrid, Ciudad Universitaria s/n, Madrid, Spain. (corresponding author to provide phone: 0034914533535; fax: 0034913365876; e-mail: saparicio@grpss.ssr.upm.es).

J. Perez is with the ETSI Telecomunicación, Universidad Politécnica de Madrid, Ciudad Universitaria s/n, Madrid, Spain (e-mail: jperez@grpss.ssr.upm.es).

A. M. Bernardos is with the ETSI Telecomunicación, Universidad Politécnica de Madrid, Ciudad Universitaria s/n, Madrid, Spain (e-mail: abernardos@grpss.ssr.upm.es).

J. R. Casar is with the ETSI Telecomunicación, Universidad Politécnica de Madrid, Ciudad Universitaria s/n, Madrid, Spain (e-mail: jramon@ grpss.ssr.upm.es).

978-1-4244-2144-2/08/$25.00 ©2008 IEEE

(Cell-ID). A similar approach with Bluetooth has been also considered in [9]. There, distance from sensors is estimated using inquiry reports issued at different cyclic power levels, meanwhile our system does not vary the transmitted power.

Regarding the fusion methods, in most of the contributions above location is met independently with every single technology; then, results are compared or combined to obtain a final estimated position. An interesting algorithm is presented in [15]. As we will describe in section IV, in our fusion procedure, processing WiFi measurements the final position is determined from a previously enclosed zone (Cell) estimated by Bluetooth measurements. Therefore, technologies complement each other and no weight has to be assigned to previous independent estimated locations.

III. WLAN AND BLUETOOTH IN LOCATION SYSTEMS

A. WLAN

Location in indoor environments are challenging because of the reflections, absorptions and multi-path phenomena suffered by the RF signals. Hence, LOS dependent parameters such as time of flight (time of arrival - TOA, time difference of arrival - TDOA) or angle (angle of arrival – AOA) based measurements used by other technologies are unsuitable. Moreover, most of these techniques need specialized hardware to extract the information.

One of the most well-known location techniques used with 802.11x wireless LAN [2] is based on fingerprinting. It is based on the measurements of the RSS from the Access Points (APs) and infers an estimated position by means of non-geometrical algorithms. The actual RSS vector of values measured in the client (as many values as APs displayed in the covered area) is compared with the vectors of values of each point of the target map, previously measured and stored in a data base in an off-line phase. Finally an estimated location is calculated applying different distance algorithms (Euclidean, k-nearest Neighbors, etc.).

Specialized hardware is not needed to extract the RSS value; it can be directly read from the wireless card. However, this method has some limitations. For example, it is completely dependent on the target area that we want to cover. Any change in the distribution of the furniture, walls or even people walking along the area will substantially vary the RSS readings. Two kinds of problems are derived from these modifications. Firstly, sudden changes in the received RSS when continuous location is being carried out cause impossible deviations of several meters for the target device's location just in one second. These wrong locations are called outliers, and need to be suppressed to gain accuracy. Secondly, when variations in the environment are not occasional, former fingerprints in the database become obsolete causing steady errors in the location sensing. Systems that refresh the database are one of the solutions implemented to minimize this last problem.

With all its pros and cons, average precision with this technique has been reported to be around 3 m in RADAR. This accuracy may be improved using more APs or including fingerprints from more coordinates in the map, by means of a more dense data base.

B. Bluetooth

Bluetooth is a widely spread short range wireless technology used to connect computers, mobile/smart phones and peripherals. This proliferation has led many researchers, in the last few years, to investigate the use of this technology to implement location systems. In this section, we will describe the parameters selected to estimate the position in those systems.

RSSI and Link Quality in Bluetooth. RSSI in Bluetooth is obtained from the comparison of the received power level against two thresholds that determine the golden receive power range (GRPR), an interval of approximately 20 dB (it might vary depending on the hardware) in which the RSSI value is zero. Fig. 1 shows the ideal correspondence between RSS and received power level, where GRPR is the horizontal line in the middle of the graphic. Assuming that receive power decreases proportionally to the square of distance to the transmitter, we can infer a relation between RSSI and distance to the transmitter.

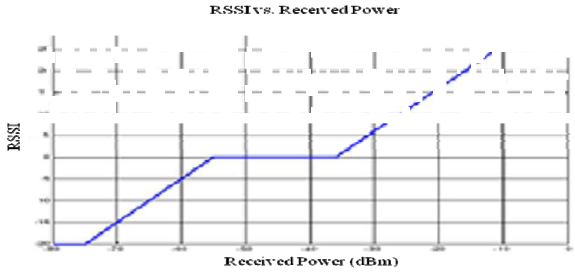

Fig.1. Ideal Correspondence between Received Power Level and RSSI in Bluetooth Devices [17].

On the other hand, Link Quality (LQ) is a discrete value varying from 0 to 255 which indicates the quality of the connection established between two Bluetooth devices. There is no specification that exactly defines how it varies; thereby it is strongly dependent on the vendor. Empirical tests show that the higher the link quality value, the better the link is. Therefore, we can also assume that LQ degrades with distance and use it for location estimation systems.

The majority of the works that have developed a Bluetooth-based location system have used RSSI to estimate the position [8], [10], as well as LQ [16]. Many works [17], [11] have tackled the golden range. We opted for a symbolic location based on Cell Identification depending on the RSSI received value. A common drawback in both RSSI and LQ parameters is the time required to extract the value from the client. A piconet should be formed between the two Bluetooth devices, receiver and transmitter, which means an average time of 2.5 s, without an ensured maximum. This process should be repeated with each target client in the range, thus when more than three clients in the area needs to be located delays become unacceptable. We were able to configure the inquiry process for extracting the RSSI without connection; in the covered area the average time was less than 1 s. The basics of this method and the way it is merged with the WLAN location calculations are described in section IV.

IV. The Fusion Algorithm

The proposed algorithm aims at determining the location of an object. It is based on the previous existence of a Bluetooth RSSI and a WiFi RSS map. Two distributions of access points are assumed: one consisting of Bluetooth stations and another one consisting of WiFi stations.

A. *Bluetooth map*

The first step is to build a Bluetooth map. We have implemented a program that constructs a Boolean function. Using the Friis formula and empirical results, we simulate, for every point of the map, the RSSI received from each Bluetooth station. For that purpose, we formulate a propagation model that provides a relationship between the received power (P_{RX}), the transmitted power (P_{TX}) and the distance (d) between transmitter and receiver.

$$P_{RX} = P_{TX} + A - 10\eta \log(d) \qquad (1)$$

In (1), A is a constant term and η is the path loss exponent.

Based on the concepts of [18], some experiments can be made to compute the path loss exponent η and the constant term A for a given transmitted power.

We have also considered that walls introduce a different attenuation depending on what they are made of. Using the experimental data we divide the covered zone in several crown-shaped distributions taking different thresholds, as explained below.

The Bluetooth map is then built as follows: if for each Bluetooth AP the simulated RSSI for each point is greater or equal than a certain threshold, it is considered to be within the selected zone of that AP, and a value of 1 is assigned to the point, otherwise a value of 0 is assigned. Performing such process for a number of different thresholds the outcome has the form of crown-shaped distributions that compose our Bluetooth map.

The crown shapes are, in fact, extremely irregular since they depend on many factors such as interferences due to obstacles present in the covered area and multiple reflections as illustrated in Fig. 2.

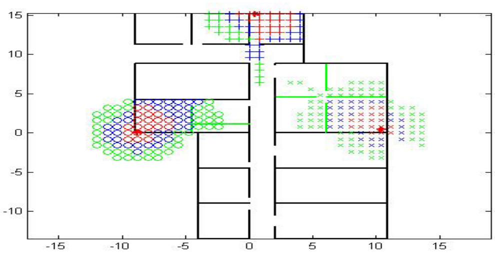

Fig. 2. Areas covered corresponding to 3 Bluetooth APs on a deployment at UPM Telecommunication Engineering School. The threshold values considered are -76,-74 y -71 (RSSI).

B. *WiFi map*

The second step is to create a WiFi map. For constructing that map we have used fingerprinting. We have measured the RSS received from the WiFi APs for each green point in the figure below.

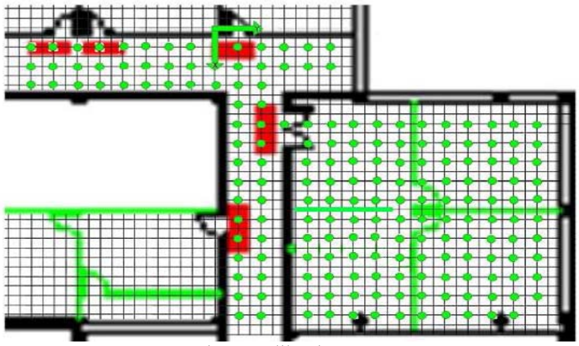

Fig. 3. Calibration map.

In a previous work we have simulated this map using a similar method to the one used for Bluetooth [19].

C. *Localization method*

Knowing the zone where the target object is located with respect to every Bluetooth station and the RSS received from every WiFi station, the location of the object was computed.

Firstly the zone of the target object to be localized is compared with our Bluetooth map and we obtain the coordinates of the points inside the crown where the object is located. We consider the points of the Bluetooth map that have the same Boolean value than the target object for each Bluetooth AP and threshold. Secondly we select from the WiFi map only the points inside the previous crown and then, the actual RSS vector of values received from the target object (as many values as APs displayed in the covered area) is compared with the vectors of values of each point of the WiFi map. The position of the object is obtained using the minimax distance and the same method as in [20].

V. Enhanced Algorithm

The previous algorithm works very well in a simulated layout considering that Bluetooth measurements determine the precise zone where the target object is located [19]. But in a real layout, many factors affect the computation of that zone, such as interferences due to obstacles present in the covered area and multiple reflections. This may lead to the selection of a zone where the target object is not located. To overcome this problem, we developed an enhanced algorithm. Instead of taking only the initial zone selected by Bluetooth measurements into account, we consider the union of several zones considering that Bluetooth measurements could be erroneous.

Thus, for every AP we will consider that the estimated crown is erroneous and the received power level from the target object actually fits either the upper or the lower crown. If we proceed with this method in every AP and we consider every combination of error between APs, the resulting intersections draw as a result a Cell junction as shown in Fig. 4.

Here we consider the case of 3 Bluetooth APs, 3 threshold values and we assume that the crown shapes distributions are really crowns.

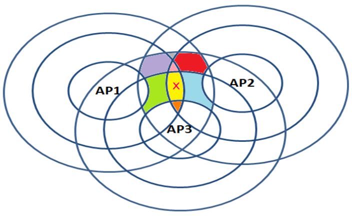

Fig. 4. Union zone example consider for 3 Bluetooth APs.

The possible zone obtained using the Bluetooth map is the yellow intersection. Afterwards we perform the enhanced algorithm described above that will guide us to the points inside the colored intersections shown, improving the reliability on the estimated area.

VI. Results

In this section the localization results in a real layout are presented. Some real experiments were performed to localize a real target object using a simulated Bluetooth map and a calibrated WiFi map.

The results presented in this paper are based on an actual WiFi deployment at UPM Telecommunication Engineering School. The distribution of APs is shown in the map in Fig. 5 for WiFi stations and in Fig. 6 for Bluetooth stations. Black lines represent concrete walls and the green ones are glass and plastic walls.

The Bluetooth attenuation considered is 4 and 1.5 (RSSI) respectively.

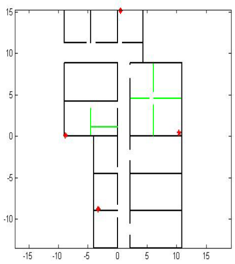

Fig. 5. WiFi access points.

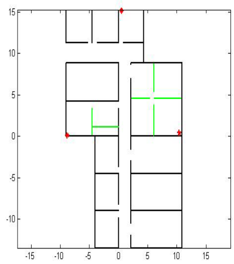

Fig. 6. Bluetooth access points.

Based on the concepts of [18], some experiments have been made to compute the path loss exponent η and the constant term A of the Friis formula for a given transmitted power. A Bluetooth AP and a PDA have been used to measure the RSSI of the received packets for different distances between transmitter and receiver.

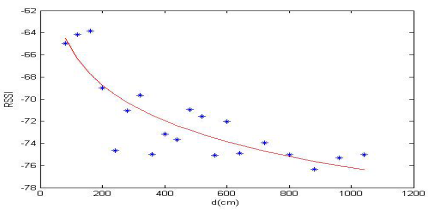

Fig. 7. RSSI vs. distance.

The experimental data (blue dots) are fitted using (1) (solid red line), see Fig. 7. From the fit in Fig. 7, values for the path loss exponent η and for the constant term A were obtained: η=1.0680 and A=-97.5712.

To build the Bluetooth map, we were looking for the minimum number of Bluetooth APs and the minimum number of different thresholds that satisfied that i) the whole map area was covered and ii) the coverage intersections approximately defined the different room areas.

This was accomplished with 3 Bluetooth APs and 3 different thresholds -90, -86 and -81 (RSSI), see Fig. 8.

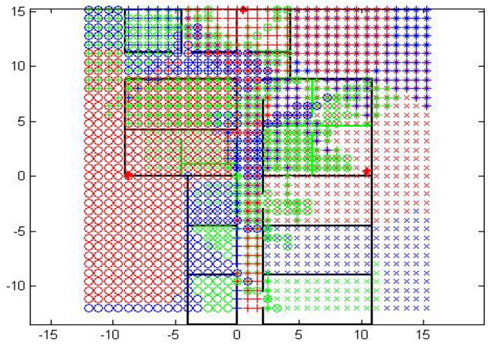

Fig. 8. Areas covered corresponding to 3 access points. The red color represents a threshold value of -81, the blue color for -86 and the green one for -90 (RSSI).

Knowing the zone where the real target object is located with respect to every Bluetooth station and the RSS received from every WiFi station, the computation of the position of that object was made. We computed the Bluetooth RSSI and the WiFi RSS received from every Bluetooth and WiFi station respectively for each real target object. For the localization of the real target object using both technologies we considered the enhanced algorithm. We tested the localization method using both technologies and using only WiFi for several points around the map, Fig. 9.

Fig. 9. Distribution of points where the algorithm has been tested.

In Table 1 we summarize the average error obtained for the localization of several real target points using both technologies and using only WiFi. By average error we mean the average deviation for 100 measurements of each real target point.

Table 1
Average error obtained for the localization of the target points using only WiFi and using Bluetooth-WiFi with 3 Bluetooth APs.

Points	**1**	**2**	**3**	**4**	**5**	**6**	**TOTAL**
WIFI	2.39	1.34	3.28	3.21	2.48	3.45	**2.69 m**
BTWIFI	2.39	1.83	2.42	2.74	2.15	2.42	**2.32 m**

The localization results obtained using the fusion of Bluetooth and WiFi are better than using only WiFi. The fusion method improves in 40 cm on average the WiFi localization method. We conjecture that this improvement is due to the elimination of Outliers thanks to the Cell Identification performed by Bluetooth.

VII. CONCLUSIONS AND FUTURE WORK

We presented in this paper the results obtained using the fusion of technologies in indoor location systems. We selected to fuse Bluetooth and WLAN and we proposed a method based on Cell-ID and fingerprinting. Firstly, using Bluetooth measurements a zone is enclosed where the target device is located. Afterwards, processing WiFi measurements the RSS readings of the target object are compared only against the fingerprints of the points within the previously determined zone and the position of this object is obtained. We conjecture that outliers, which were culprit of inaccuracy in fingerprint based methods, are thereby eliminated thanks to the Cell Identification performed by Bluetooth.

In a previous paper [19], some simulated results were presented. Simulated Bluetooth and WiFi maps were created. For the construction of the Bluetooth map we considered the same propagation model as the one used for WiFi. We assumed that using Bluetooth measurements the precise zone where the simulated target object is located can be computed.

In this paper some real experiments were done to localize a real target object. We show the localization results obtained using a simulated Bluetooth map and a calibrated WiFi map. Some Bluetooth real measurements were used for the construction of the Bluetooth map. We introduced an enhanced algorithm to overcome the problem of selecting a zone where the real target object is not located. The localization results were better using the fusion of Bluetooth and WiFi than using only WiFi.

For the construction of the WiFi map we used fingerprinting and for the Bluetooth map we formulated a propagation model taking into account some real measurements and the attenuation produced by walls. In a future work, it would be interesting to design accurate models including other important factors such as interferences due to obstacles present in the covered area, multiple reflections. This will lead us to avoid the fingerprinting and to obtain more accurate simulated maps. Research aimed to improve both Fingerprint and Cell-ID methods will be developed. Monitor APs that refresh the Fingerprint database to upgrade its robustness, or the deployment of a Bluetooth ad-hoc network to add mobility to the Bluetooth APs are also being studied and considered.

REFERENCES

[1] A. M. Bernardos, P. Tarrío, J. R. Casar, "A Taxonomy of Mobile Location-Based Services", *International Conference on e-Business*, Barcelona, 2007.

[2] 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*, Vol.2 pp. 775-784. IEE Proceedings.

[3] A. Harter, A. Hopper, P. Steggles, A. Ward, P. Webster, "The Anatomy of a Context-Aware Application". *5th Annual ACM/IEEE Int. Conference on Mobile Computing and Networking*, pp: 59-68. Seattle USA, Aug 1999.

[4] L. M. Ni, Y. Liu, Y. C. Lau, A. P. Patil, "LANDMARC: Indoor Location Sensing Using Active RFID", *Wireless Networks (eds.)* Springer Netherlands, pp: 701-710, 2004.

[5] N. B. Priyantha, A. Chakraborty, H. Balakrisnan, "The Cricket Location-Support System", *6th Int. Conference on Mobile Computing and Networking*, pp: 32-43, Aug 2000.

[6] R. Want, A. Hopper, V. Falcao, J. Gibbons, "The Active Badge Location System", *ACM Transactions on Information Systems*, vol.10, no.1, pp.:91-102, Jan 1992.

[7] J. Hightower, G. Borriello, R. Want, "SpotON: An indoor 3D Location Sensing Technology Based on RF Signal Strength", *UW CSE,* Technical Report #2000-02-02.

[8] J. Yipin Ye, "Atlantis: Location Based Services with Bluetooth", *Master´s Thesis*, Brown University, 2005.

[9] F. Forno, G. Malnati, G. Portelli, "Design and Implementation of a Bluetooth ad hoc Network for Indoor Positioning", *IEE Proceedings-Softw.*, vol. 152, pp: 223-228, 2005.

[10] S. Feldmann, K. Kyamakya, A. Zapater, Z. Lue, "An Indoor Bluetooth-Based Positioning System: Concept, Implementation and Experimental Evaluation", *International Conference on Wireless Networks*, Las Vegas, 2003.

[11] U. Bandara, M. Hasegawa, M. Inoue, H. Morikawa, "Design and Implementation of a Bluetooth Signal Strength Based Location Sensing System", *Radio and Wireless Conference, IEEE*, pp: 319-322, 2004.

[12] P. Hii, A. Zaslavsky, "Improving Location Accuracy by Combining WLAN Positioning and Sensor Technology". Monash University, Melbourne, 2005.

[13] A. Matthieu, J. L. Crowley, V. Devin, G. Privat, "Localisation Intra-bâtiment Multi-technologies: RFID, WiFi et Vision", *Proceedings of the 2nd French-speaking conference on Mobility and ubiquity computing*, pp: 29-35, 2005.

[14] D. Pandya, R. Jain, E. Lupu, "Indoor Location Estimation Using Multiple Wireless Technologies", *The 14th IEEE 2003 Int. Symposium on Personal Indoor and Mobile Radio Communication Proceedings*, pp.:2208-2212.

[15] J. Myllymaki, S. Edlund, "Location Aggregation from Multiple Sources", *Proceedings of the Third Int. Conf. on Mobile Data Management*, 2002.

[16] A. Genco, "Three Step Bluetooth Positioning", *Location and Context Awareness*, pp: 52-62, 2005.

[17] T. W. Bielawa, "Positioning Location of Remote Bluetooth Devices", *Thesis of M. of Science in Electrical Engineering*, Virginia Polytechnic Inst. And State University, 2005.

[18] P. Tarrío, A. Bernardos, J. R. Casar, "A Transmission Rate and Energy Design for Power Aware Localization in Ad Hoc and Sensor Networks", *The 18th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications* (PIMRC'07).

[19] J. Pérez, S. Aparicio, A. M. Bernardos, J. R. Casar, "An Indoor Location System Based on Bluetooth and WLAN", *Proceedings of the Workshop on User-Centric Technologies and Applications*, pp. 77-86, Salamanca, 2007.

[20] E. Collado, "Diseño y desarrollo de algoritmos de localización de dispositivos en redes inalámbricas para provisión de servicios móviles", *Master´s thesis,* ETSIT-UPM, 2007.

[21] J. Hightower, G. Borriello, "Location systems for ubiquitous computing", *IEEE Computer*, Vol. 34 no. 8, pp. 57-66, Aug 2001.

[22] J. Pérez, "Integración de tecnologías inalámbricas para la localización de dispositivos móviles en interiores", *Master´s thesis*, ETSIT-UPM, 2008.

[23] D. Cotroneo, S. Russo, F. Cornevilli, M. Ficco, V. Vecchio, "Implementing Positioning Services over an Ubiquitous Infrastructure", *Proceeding of the Second IEEE Workshop on Software Technologies for Future Embedded and Ubiquitous Systems*, pp: 14-18, 2004.

[24] C. Flora, M. Ficco, S. Russo, "Indoor Positioning for Location-Aware Applications on Java-Based Mobile Devices", *Workshop on Java Technologies for Real-Time and Embedded Systems*, 2004.

[25] T. M. Fernández, J. Rodas, C. J. Escudero, D. I. Iglesia, "Bluetooth Sensor Network Positioning System with Dynamic Calibration", *IEEE ISWCS,* 2007.