A Novel Approach to Indoor Location Systems Using Propagation Models in WSNs

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Abstract— **This paper describes a location system for persons and objects in an indoor environment, where wireless nodes can include sensors and provide unique identifiers. The system nodes, using ZigBee technology, can function as RFID tags, having each one a unique EPC identification number. Sensors can be associated with the wireless nodes Zigbee to create applications for home, health and traffic control.**

Existemt location systems are analyzed, with emphasis on indoor location systems.The implemented location algorithm includes a propagation model based on the wall attenuation factor together with triangulation.

A variety of tests were carried out in an indoor environment. Results demonstrate that the location system is viable, showing itself to be effective, flexible and easily adaptable to various locations.

Keywords - Location, Propagation, Triangulation, WAF, ZigBee, Wireless.

I. Introduction

History shows that progress and technological development are inevitable, actually becoming a need in the globalise world of nowadays. Telecommunications are currently essential in world economy operations of any modern society, being, wireless network systems one of the greatest developments in the area of communications. An example of such a network, is a WSN (Wireless Sensor network), where spatially distributed autonomous devices, equipped with sensors, are used in environment monitoring, traffic control, healthcare, home automation, etc. RFID (Radio Frequency Identification) is also a wireless technology. The development of RFID, besides the advantages in several areas, has also been a starting point to technological evolution in location systems. There has been a rising interest in location techniques that has been motivating allot of research in this area. In location systems there are two types of scenarios: outdoor location and indoor location. Each one of these scenarios presents itself with different characteristics and challenges, being that indoor location systems are the hardest to implement given its complexity and all the factors that have to be considered. RFID and WSN can be used together. Furthermore, generations of RFID tags include sensors, and WSNs that require automatic identification mechanisms [1].

Lately, there has been a growing interest in the integration of RFID and WSN (Wireless Sensor Network) systems. These technologies can originate the development of a variety of applications, particularly in terms of location, in residential environments, corporate environments and critical infrastructures worldwide [1]. ZigBee is a wireless technology that is well suited for WSN. Besides, it can be used to build active RFID tags. The use of RFID technology with ZigBee protocol provides the study of effective, low energy consumption, and financially accessible location systems. In this paper we will explore the use of Zigbee in order to build an indoor location system. Based in this system that locates objects in indoor environments, objects can be identified and sensing variables can be measured.

It's precisely the fusion of RFID with WSN that is the starting point of this work. The goal is make use of the RFID capabilities in automatic identification of people and objects, based on a ZigBee network, to develop an indoor location system. In order to develop a location system it's necessary to study the existing location methods and algorithms, especially those that focus in indoor location. It's important to maximize the advantages offered by the use of RFID and ZigBee together. Knowing that the goal is to achieve a system that is both easily adaptable to various location environments and flexible, it's necessary to give more attention to the location methods that use electromagnetic waves propagation models.

A starting point to the development of an indoor location system is the definition of the location method. In this paper, we propose a location system that uses triangulation together with a propagation model. The main obstacles in using triangulation are: the selection of three network devices and the estimation of the distance between fixed and mobile devices. The goal in the selection of the three network devices is to have them as closest as possible to the mobile device improving the accuracy of the system. In order to estimate the distance between fixed and mobile devices, RSSI (Received Signal Strength Indicator) measures are made so that the distance can be estimated through the use of a propagation model. The use of RSSI leads to a certain degree of inaccuracy due to multipath effect, mainly caused by the indoor environment of a building as well as the distance between a transmitter and a receiver.

The paper is organized as follows. After this introduction, section 2 presents the state of the art concerning location systems, emphasizing indoor location. The indoor propagation models are described in section 3. Section 4 presents the developed system. In section 5, the system characterization is presented, being the results discussed in section 6. Section 7 presents some conclusions.

II. Location Systems

The success of the GPS system for monitoring and locating objects in outdoor environments, encouraged the application of similar techniques to indoor environments. Unfortunately these techniques are not a valid option for indoor location [2]. These difficulties motivate much research to develop new techniques. With the enormous growth and widespread use of short range wireless technologies, such as Bluetooth for wireless personal area networks (WPAN), WIFI (802.11) for wireless local area networks (WLAN) and ZigBee for wireless sensor networks (WSN), many academic and commercial systems are based measurement of the radio signal propagation.

In [3] present a widely accepted taxonomy to classify location techniques adopted by existent location systems. This taxonomy divides the techniques in three different groups: triangulation, proximity and scenario analysis.

A. Taxonomy

1) Triangulation: Triangulation is a technique of determining the location of a object, based on geometric properties of triangles and mathematical formulation. Two different techniques of triangulation exist: lateration and angulation. Lateration uses distances and angulation uses angles to determine the position of an object in a coordinate system (figure 1).

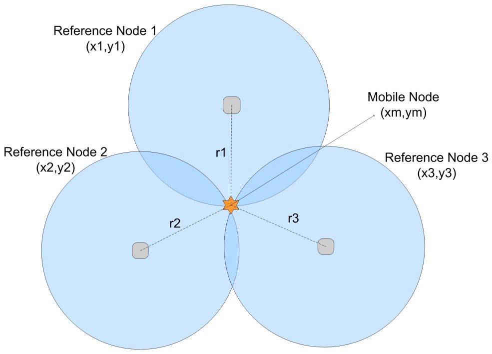

Fig. 1. Lateration

Lateration determines the position of an object by measuring its distance from multiple reference positions. In a bi-dimensional coordinate system distances to 3 non-collinear need to be measured (figure 1). Lateration systems measure distances with different techniques: direct measurement, using a physical action; time-of-arrival, measuring the time it takes a signal to travel between the object and the reference point at a known velocity; or attenuation, measuring the attenuation in the propagation of a radio signal between the object and the reference point. As the strength of radio signals is inversely proportional to the square of the distance from the source, distance is calculated based on send and receive strength.

Angulation uses angles to determine the position of an object. In a 2- dimensional Cartesian coordinate system, two angles and the distance between the reference points are used (figure 2).

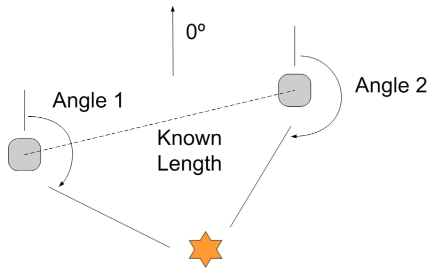

Fig. 2. Lateration

2) Proximity: Proximity based localization techniques obtain the position of an object by identifying a known reference near the object. Detection of proximity is usually achieved by: detecting physical contact with the object, using sensors; monitoring wireless cellular access points, identifying when an object is in the range of an access point; or by observing automatic identification systems. If an object is identified by an automatic system, its location can be inferred.

3) Scene Analysis: Scene analysis techniques are based on the observation of the environment where the objects are to be located. The characteristics of the environment are observed and then compared to the characteristics of a previous observation, in order to determine the location of the objects.

Static scene analysis typically consists of first phase where a pre-characterization of the environment is carried out. Obtained data are stored in a database. Observed characteristics are compared to the stored data to derive the location. Differential scene analysis tracks the difference between successive scenes to estimate location.

4) Location Fingerprinting: Location fingerprinting is a static scene analysis technique that uses radio frequency measurements to characterize the environment. Multiple radio nodes are distributed in the entire location area, usually according to a rectangular grid of points.

During the pre-characterization phase, generally called off-line phase, measurement of the received signal strength (RSS), from multiple fixed nodes, is performed. The collection of RSS values at a point on the grid is called the location fingerprint of that point. Location fingerprints are stored in a database. As RSS values fluctuate along the time, several values are measured and statistical processing is applied to build a reliable database. During the second phase, the on-line phase, the object to be located (mobile node) collects the RSS values collected from multiple fixed points. An algorithm estimates the location of the object and reports the estimated position information. The most common algorithm to estimate the location computes the Euclidean distance between the measured RSS values and the location fingerprints. Other deterministic, such as nearest neighbor or neural networks and probabilistic algorithms based on statistical learning theory and Bayesian interference are also used.

III. Indoor Propagation Models

In radio frequency indoor location system, time and angle of arrival methods are not used because signals are affected by the multipath effect. Triangulation is implemented based on the attenuation methods, using models to relate the received power with distance.

Indoor electromagnetic waves propagation, especially inside a building, is characterised by reflections, diffractions and dispersion in the internal structures. The transmitted signals arrive to the receiver through multiple paths, originating fluctuations in the received signal. This effect, called multipath propagation, is affected by the type of materials used in the construction of the building and by the surrounding objects. Therefore, it is very difficult to predict the strength of the received signal.

There are models that take into accounty the constructive and destructive nature of multipath to relate the received power with the distance between transmitter and receiver. Rayleigh Fading Model [4] and Rician Distribution Model [5] are widely used, but they present some drawbacks. The Rayleigh Fading Model describes the small-scale rapid amplitude fluctuations in the absence of a strong received component. It assumes that all signals reaching the receivers have equal strength, which is not a realistic approach. A dominant line-of-sight (LoS) component is not accounted for by this distribution. The Rician Distribuition Model takes in account that a strong path exists in addition to the low level scattered path. This model is very appealing, but it is very difficult to determine its parameters, as this requires to physically isolate the direct wave from the scattered components [2].

A. *Wall Attenuation Factor Model (WAF)*

The WAF model [2] is quite attractive, given its ability to describe the slow fading phenomenon and the attenuation in the signal propagation introduced in indoor environments. It derives from the floor attenuation model (FAF) [6], where an attenuation factor is used to estimate the signal intensity in different floors of a building. In the WAF model the attenuation factor permits to predict the behaviour of the signal propagation, when walls are the main obstacle [2]. Equation 1 indicates how the attenuation influences the received signal strength.

$$P(d)_{[dBm]} = P(d_0)_{[dBm]} - 10n\log\left(\frac{d}{d_0}\right) - \begin{cases} nW * WAF & ,nW < C \\ C * WAF & ,nW \geq C \end{cases} \quad (1)$$

In equation 1, n indicates the rate at which the attenuation of the signal increases with the propagation distance, $P(d_0)$ is the received signal strength at a distance of reference d_0 and d is the distance between the transmitter and the receiver. In the attenuation factor, the C parameter accounts for the number of walls for which the attenuation factor (WAF) stops influencing the signal; nW is the number of obstructions (walls) between the transmitter and the receiver; and WAF is the value for the attenuation of each wall.

B. *The Adjusted Motley-Keenan Model*

The adjusted Motley-Keenan model [7] was developed based on the Motley-Keenan model [8]. This last model, represented by equation 2, is similar to the WAF model, but does not limit the number of walls influencing the signla attenuation. In equation 2, PL_d is the the attenuation at 1 meter of distance between transmitter and receiver, n the attenuation decay rate with distance, N the number of walls between transmitter and receiver, and k_i the number of type i walls, having attenuation of Lw_i.

$$PL(d)_{[dB]} = PL_{d[dB]} + 10n\log(d) + \sum_{i=1}^{N} k_i Lw_i \quad (2)$$

The adjusted Motley-Keenan model also considers the thickness of the walls. In equation 3, L_0 is the attenuation of a reference wall with thickness e_0, and e_i is the thickness of a wall of type i placed between the transmitter and the receiver. The adjusted term substitutes, i in equation 2, the term $\sum_{i=1}^{N} k_i Lw_i$ in order to account for the thickness of the walls originating equation 4.

$$AdjustedTerm = \sum_{i=1}^{N} k_i L_0 2^{\log_3\left(\frac{e_i}{e_0}\right)} \quad (3)$$

$$PL(d)_{[dB]} = PL_{d[dB]} + 10n\log(d) + \sum_{i=1}^{N} k_i L_0 2^{\log_3\left(\frac{e_i}{e_0}\right)} \quad (4)$$

IV. Developed System

The developed system creates a WSN with ZigBee technology to implement an indoor location system. This system was developed in order to have an automatic identification system using RFID. In the WSN one of the devices is mobile being the target of location. The other devices are placed in pre-defined positions. The final objective is to place the mobile device on a person or object in order to determine his location and identify him through WSN and RFID technology.

A. *System Architecture*

The ZigBee protocol emerges as a complement to the IEEE 802.15.4 standard, guaranteeing reliability and safety as well as a low energy consumption [14]. ZigBee using devices shall have a maximum range of 150 meters, depending this value of the environment and energy consumption of the using application.

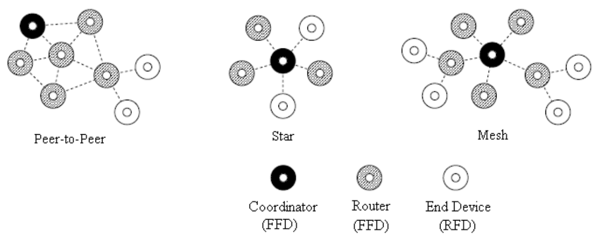

Fig. 3. Network Topology

The IEEE 802.15.4 standard defines three types of network topologies: star topology, peer-to-peer topology and mesh network [14]. Figure 3 shows the three topologies.

The star topologies require at least one FFD (Full Function Device) device functioning as network (WPAN - Wireless Personal Area Network) coordinator. The communication is established between devices and the network coordinator. The WPAN coordinator is normally powered by the electric network and the remaining devices (FFD or RFD (Reduced Function Devices)) by batteries.

In peer-to-peer topologies there also exists a WPAN coordinator, being that in this topology all devices can communicate with each other. The configuration can be found in control and industrial monitoring applications using WSNs. A mesh network is no more than a particular case of the peer-to-peer topology, where most of the devices are FFDs.

Given this, and because ZigBee distinguishes the concept of physical devices (FFD, RFD) using the notion of logical devices, we propose a network that consists of a mobile device that acts as a ZigBee Coordinator and several fixed devices acting as ZigBee End Devices. The ZigBee Coordinator is the first type of logical device, assuming a role much similar to a coordinator in the IEEE 802.15.4 coordinator and is responsible for: initiation, maintaining and manage a network. In the ZigBee hierarchy, next in line is the ZigBee End Device that is the final point in the network structure [15]. The proposed network topology is very similar to the peer-to-peer topology in the IEEE 802.15.4, where the goal is to have all the devices capable of communicate with each other.

We propose a system that is composed of a central server that executes the location algorithm as well as initiates the network. The central server can be located in the mobile device, allowing the device to locate himself, or any other location in the network being that because we are using ZigBee technology all the devices can communicate with each other.

B. Propagation Model

We use a propagation model based on the WAF propagation model [2], making the WAF parameter equal to zero (equation 5). The walls are not always an obstacle between the mobile and the fixed devices. Therefore, we adopt equation 5 instead of equation 1, but with different n and $P(d_0)$ than those used in equation 1.

Figure 1 presents an example where obstructions can exist in a certain direction but not in other directions, in the circumference. Therefore, only at the distances and in the directions where there is a presence of a wall the WAF factor is accounted for. Through this method it's possible to obtain a wide range of different WAF values for the same distances.

During the first phase, where RSS values are collected to determine n and $P(d_0)$ in equation 3, the RSS values that are affected by the presence of a wall are identified (through visual inspection of the location environment).

To those RSS values the value of the WAF factor (previously determined for respective distances and directions) will be subtracted in order to minimize the influence of the walls on the characterization of the RF signal in the location environment. This way the WAF factor is taken into account and it is reflected on the determined n and $P(d_0)$ parameters, instead of being a constant (equation 1) used at determined distances in all directions [17].

$$P(d)_{[dBm]} = P(d_0)_{[dBm]} - 10n \log\left(\frac{d}{d_0}\right) \tag{5}$$

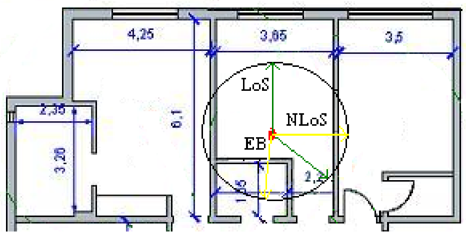

Fig. 4. Line of Sight

C. Location Algorithm

The goal for this location algorithm is to allow the location of the mobile device within certain areas of the indoor environment. The proposed algorithm is not intended for a precise location of the mobile device but to distinguish where in a certain division of a room the device is located.

Knowing that, the developed location algorithm is divided in two steps. Firstly, a propagation model is used to calculate the distances between the fixed devices and the mobile device, based on the received signal strength indicator (RSSI). This phase involves the definition of the propagation models parameters. These parameters are defined based on a previous characterization of the of RF signals in the location environment in terms, by collecting the RSS values. This characterization is much like the off-line phase used in scenario analysis methods [3]. Next, knowing the distances between the fixed and mobile devices and using a triangulation algorithm (see section D), it is possible to determine the location of the mobile device.

D. Triangulation Algorithm

To use the system, it is necessary to define the coordinate system and the position of the fixed nodes (base stations). We adopt a 2D system, assuming that all nodes are at the same height. Knowing the positions of at least three fixed devices and their distances to the mobile device it is possible to calculate the coordinates (*x*,*y*) where the mobile device is located.

In order to estimate the three fixed devices that are closer to the mobile device, the centroid of a polygonal area as well as RSSI are used. The vertices of the polygon are fixed devices which received a beacon message from the mobile device. A preference index (FDI - Fixed Device Index) is then created so that "best" fixed devices that received the beacon messages can be chosen [16]. The FDI of FD*i* (Fixed Device) is defined by the following equation:

$$FDI_i = (1-\alpha)\left(1-\left(\frac{dist_i^c}{dist_{max}}\right)\right)+\alpha\frac{RSSI_{Ri}}{RSSI_{max}} \quad (6)$$

where $dist_c^i$ are the Euclidian distances between the centroid of a polygon and FD*i* and α is a small number $(0 \leq \alpha \leq 1)$. The values for $dist_{max}$ and $RSSI_{max}$ are defined as:

$$dist_{max} = max_{\forall i}\{dist_i^c\} \quad (7)$$

and

$$RSSI_{max} = max_{\forall i}\{RSSI_{Ri}\} \quad (8)$$

where FD*i* is an FD which received a beacon message from the mobile device. Given FDIs, the triangulation algorithm selects the three FDs with the highest FDI values for triangulation.

We implemented the Dynamic Triangular Algorithm (DTN) [10]. It is well suited for small environments it is allow complexity algorithm a requires a reduced processing time.

The DTN algorithm needs at least three sensor nodes to estimate the location of mobile device. The method discards the worst RSSI values measured by the devices and uses the best three to estimate location. It chooses the fixed device which receives the greatest RSSI value and assumes that the mobile devices location is in the mapping circle of that fixed device. The mapping circle is the estimation distance d1 between the mobile device and the closest fixed device. The DTN finds the angle θ on the mapping circle by using a cost function to pick one that best matches the observed distance. The DTN has the following steps:

1) Generation of the mapping circle: It finds the possible locations of the mobile device (x1+d1cosθ, y1+ d1sinθ) on the mapping circle by using the possible distances d2θ and d3θ between mobile user and the fixed nodes.

2) The distance of the mobile device estimation: Finds the error between estimation distances (d2 and d3) and possible distances (d2θ and d3θ).

3) The coordinates of the mobile device approximation: Determines the cost functions at each angle θ and the θ increases 1 degree each time. The DTN then searches the minimum cost function, and the θ of the minimum cost function is the estimation angle on the mapping circle. The angle θ on the mapping circle is the estimation location of the mobile device. Figure 5 describes the procedure of the DTN location algorithm.

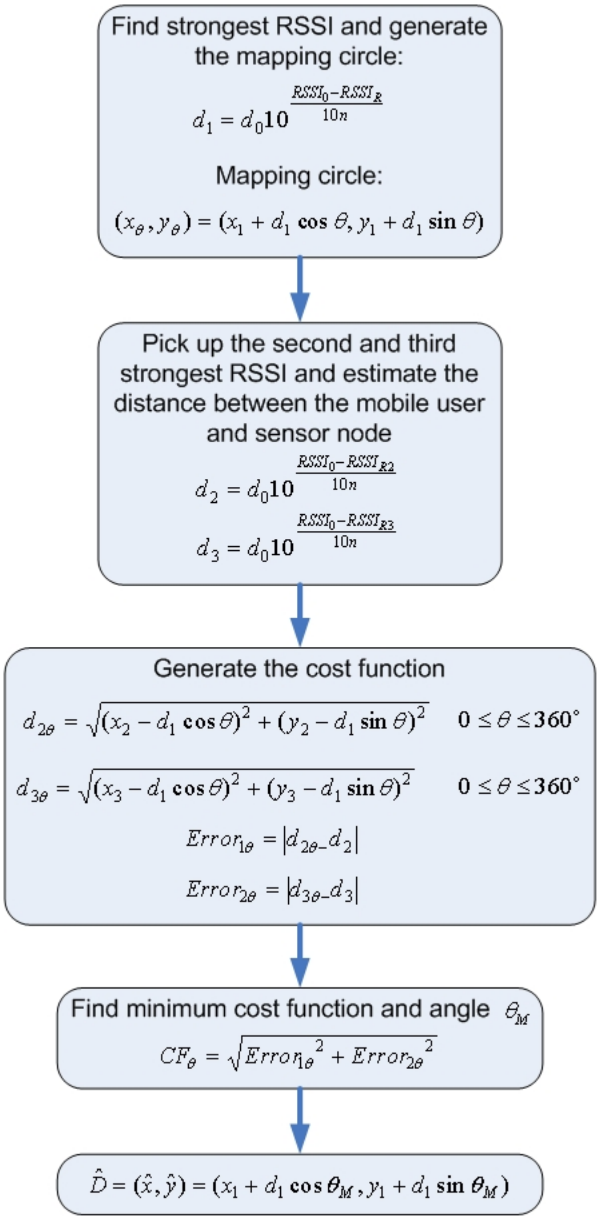

Fig. 5. Dynamic Triangular Algorithm Procedure

E. Prototype Implementation

The final system will include fixed nodes and mobile nodes. Fixed devices will be placed in pre-defined positions. They will be implemented as embedded systems. Mobile nodes can be implemented has embedded systems or objects and persons equipped with ZigBee tags. Mobile devices are the target for location and identification. Nodes will have a unique EPC (Electronic Product Code) identification number [9].

Five ZigBee nodes compose the developed prototype with four fixed nodes and one mobile node. For prototyping purposes, we used a notebook connected to a ZigBee interface through a RS-232 interface.

Fixed nodes and the ZigBee interface of the mobile node are PCB boards supporting commercially available ZigBee

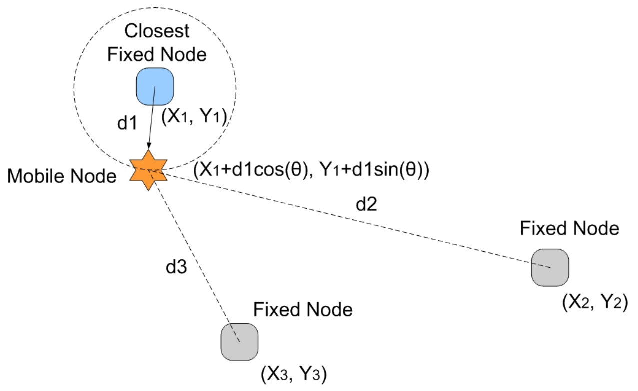

Fig. 6. Dynamic Triangular Algorithm

devices. The developed PCB board also include batteries, a RS232 interface and a USB interface. Programming of ZigBee devices and EPC code assignment is done through RS232. The USB port is used to power the mobile device through a notebook. Fixed nodes are RFD (Reduced Function Device) programmed as ZigBee End Devices. They work independently and are powered by batteries. The mobile device is a FFD (Full Function Device), being programmed as a ZigBee Coordinator. When starting, the mobile device transmits a signal in order to allow the fixed nodes, to detect it. The mobile device is responsible to transmit the received radio signal strength indicator (RSSI) to the software application that executes the location algorithm in order to determine the mobile location.

The software application also initialises the wireless network, establishing the communication between ZigBee devices. Due to hardware limitations we connected the mobile device directly to a notebook, powering the device through the USB port and using the RS-232 port to communicate. A future and more advanced system would be controlled by a server that would execute all the tasks, being the notebook no longer needed.

V. System Characterization

The prototype was installed and tested in a residential environment. The location area is shown on Figures 7 and 8. Table I shows the coordinates for each fixed device. EB1 is located at the origin of the referential.

Fixed Devices	Coordinates (x,y) in meters
Device 1	(0;0)
Device 2	(4,8;5,8)
Device 3	(0;5)
Device 4	(3,7;0)

TABLE I
Fixed Devices Coordinates

As can be seen on Figure 7, we decided to use a small area. This approach minimizes the location error. In fact, the indoor range of ZigBee devices is limited and when distances increase location errors also increase. Although, it is possible

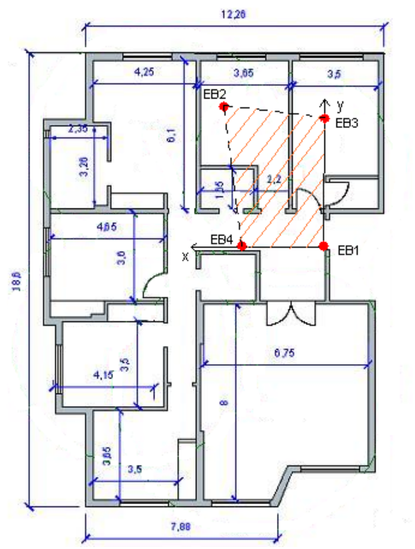

Fig. 7. Location Environment

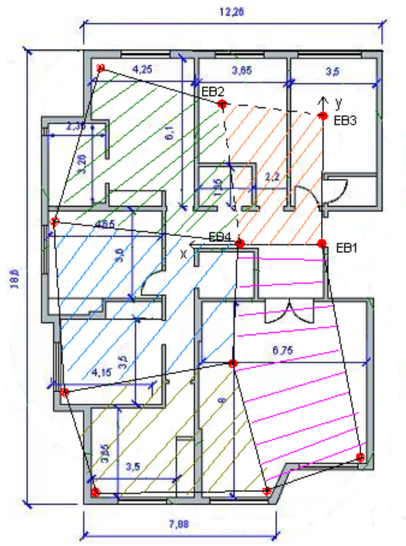

Fig. 8. Set of small location environments

to locate objects in a much larger area, using several small areas, as presented on Figure 8. Using similar small areas with small obstruction also makes easier to characterize the environment. However, the number of fixed devices need to be increased. (The number of devices shown in Figure 8 only has the purpose of illustrating the general idea behind the use of small areas!)

In order to evaluate the capabilities and reliability of the location system we analyse the prototype in different situations: without the WAF factor, introducing the WAF factor and and using an average value for the WAF factor.

The characterization of RF signals is essential to the location system, only doing this it is possible to predict the signal behaviour during propagation and determine the propagation model parameters (n and $P(d_0)$). This characterization is made through the collection of RSS values in a previous location stage (off-line).

To determine the propagation model parameters, we followed the scenario analysis described in [11]. Measuring the strength of the received signal (RSS) at the fixed devices, transmitted by the mobile device, we repeated this process moving the mobile device across the location area. RSS values were obtained in three fixed devices and, for each one, in three different directions (as presented on Figure 9). The use of three devices instead of all four is enough to determine the propagation model parameters.

Propagation model parameters were calculated for each device individually and for all devices together. Therefore, there is a specific equation for each device and an equation that can be used for all devices.

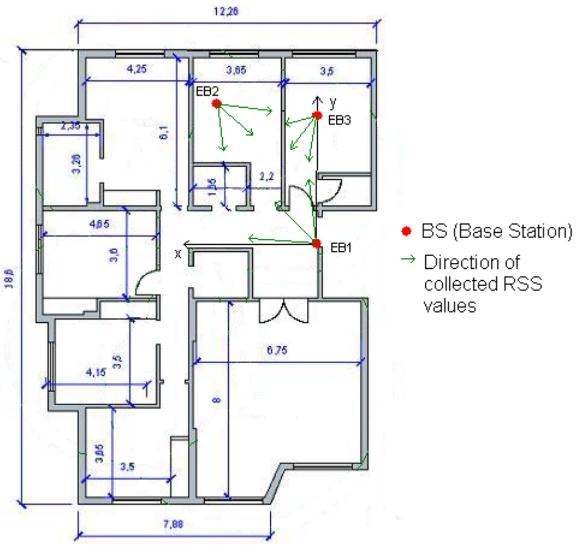

Fig. 9. Direction of collected RSS values

A. Parameter of attenuation WAF

In order to calculate the WAF value, RSS values were measured, for the same distance, with and without a wall between the fixed and mobile nodes. The WAF is the difference between the two RSS values. Table II presents WAF values , for each device and all devices together, obtained for different distances.

Distance (meters)	Device 1	Device 2	Device 3
2,5	-	4,25 dB	-
3	4,42 dB	11,5 dB	13,67 dB
3,5	17,42 dB	-	6,5 dB
4	-	18,08 dB	8,83 dB

TABLE II
WAF PARAMETERS

Table III shows the average value of WAF for each fixed device and for the set of values of all devices together.

B. Characterization of RF signals without WAF

RSS values were collected in each fixed node and in all three different directions. This RSS values permitted, by logarithmic

Fixed Devices	Average WAF
Device 1	10,92 dB
Device 2	11,28 dB
Device 3	9,67 dB
All Devices	10,58 dB

TABLE III
AVERAGE WAF PARAMETERS

regression, to calculate the attenuation ratio and the received signal strength at the distance of 1 meter. Figure 10 illustrates the use of logarithm regression and table IV presents the values obtained for the fixed devices.

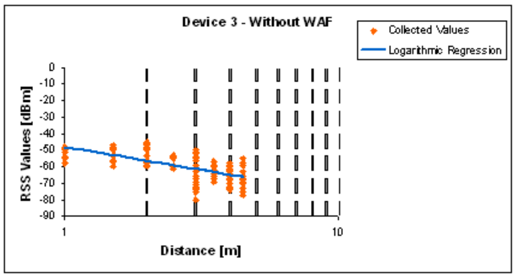

Fig. 10. Collected values for device 3

Without WAF	Attenuation Factor (n)	RSS at 1m ($P(d_0)$)
Device 1	2,382	-45,50 dBm
Device 2	3,637	-40,32 dBm
Device 3	2,806	-48,08 dBm
All Devices	3,027	-44,50 dBm

TABLE IV
CALCULATED PARAMETERS WITHOUT WAF

With the calculated values in the tested situation it was possible to plot the characteristic of the RF signal in terms of the distance using the theoretical model (propagation model) and compare it with the experimental collected RSS values. The following graphics (Figures 11 and 12) compare the theoretical model with the average of the collected RSS values at different distances.

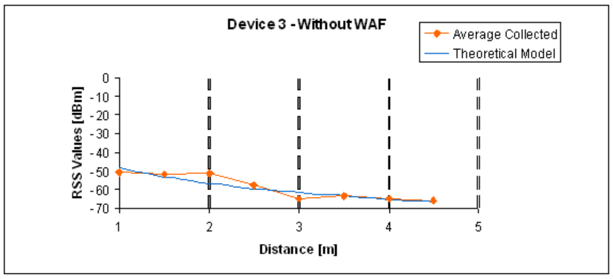

Fig. 11. Average Collected Values VS. Theoretical Model

C. Characterization of RF signals with WAF

This characterization is very similar to the first one and uses the same collected RSS values, but with the difference

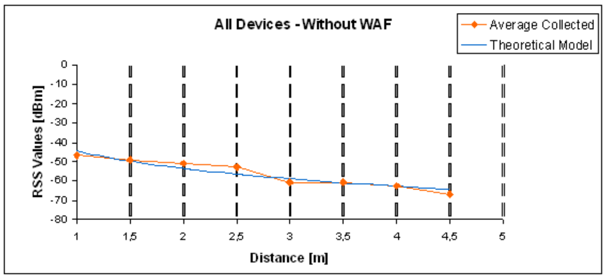

Fig. 12. Average Collected Values VS. Theoretical Model

that WAF values are now taken into account (Table I). Table V shows the calculated values of the propagation model parameters through logarithmic regression and Figures 13 and 14 show the graphics that compare the theoretical model with the average of the collected RSS values at different distances.

With WAF	Attenuation Factor (n)	RSS at 1m ($P(d_0)$)
Device 1	2,012	-45,77 dBm
Device 2	2,803	-41,12 dBm
Device 3	2,391	-48,07 dBm
All Devices	2,255	-45,21 dBm

TABLE V
CALCULATED PARAMETERS WITH WAF

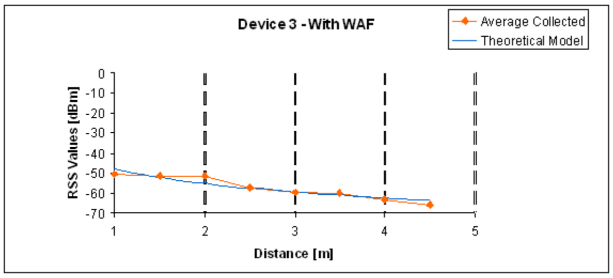

Fig. 13. Average Collected Values VS. Theoretical Model

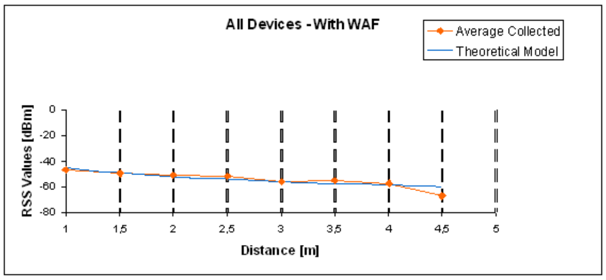

Fig. 14. Average Collected Values VS. Theoretical Model

D. Characterization of RF signals with average WAF factor

This characterization is very similar to the first two and uses the same collected RSS values, but with the difference that the average WAF values are now taken into account (Table II) . The results were not very different then those fo the characterization of RF signals with WAF factor.

VI. RESULTS

After the characterizations the location algorithm was tested. In order to do that the mobile device was placed on two different and random positions. The algorithm was tested without the introduction of WAF, with WAF and with the average value of WAF. The tests were also made for each fixed device separately and for the set of values of all devices together, in this case all fixed devices were characterised by the same propagation model equation. The tests revealed errors from 2,5 to 0,25 meters when using the developed propagation model Tables VI and VII).

Point A (1,8;4) m	Wout/ WAF	W/ WAF	All Wout/ WAF	All W/ WAF
Mob. Node Coord.	(3,14;7,25)	(2,29;6,52)	(6,54;6,50)	(3;-3,63)
Coord. Error	(1,34;3,25)	(0,50;2,52)	(4,74;2,50)	(1,20;-0,37)
Dist. Error	3,51	2,57	5,36	1,26

TABLE VI
LOCATION RESULTS FOR POINT A

Point B (0,7;4) m	Wout/ WAF	W/ Avg. WAF	All Wout/ WAF	All W/ Avg. WAF
Mob. Node Coord.	(0,54;5,65)	(0,27;4,25)	(0,72;5,86)	(0,83;4,23)
Coord. Error	(-0,16;1,65)	(-0,43;0,25)	(0,02;1,86)	(0,13;0,22)
Dist. Error	1,66	0,50	1,86	0,26

TABLE VII
LOCATION RESULTS FOR POINT B

Analysing Figures 11, 13 and 16 we can observe that, for certain locations, the introduction of the WAF parameter increased the error. However, in general, the theoretical model (equation 5) is a good approximation of the collected RSS values. The graphics relative to the deviations of the collected RSS values and theoretical model (Figures 16 and 18) confirm the previous statement. A decrease in RSS values (which translates into a decrease in error), can be observed on Figure 15 when WAF parameter is introduced. This decreased is also noticed when using the average WAF parameter.

Its also verified in the standard deviation of the collected values that at the same distance the fact that the RSS values are not always the same, influences the parameters of the model introducing an additional error. Its also verified that when the set of values of all devices together is used to calculate the model parameters it does not produce very different results of those presented when each fixed device has his own equation.

In general comparing the developed system with other systems, that mainly use location fingerprint techniques, it is possible to assume that the developed system produces results similar to other systems. Table VIII shows the typical error of other location systems. Although the location environment in which the systems were tested was larger than the one used in this paper, the fact that location fingerprint techniques usually produce more accurate results reinforces the good results achieved by the developed location system.

Location Systems	Algorithm Type	Error
RADAR[2]	Nearest Neighbour	2.13 meters
Youssef[12]	Bayesian	2.13 meters
XIANG[13]	Bayesian, RSS distribution model	1.83 meters

TABLE VIII
COMPARISON WITH LOCATION SYSTEMS

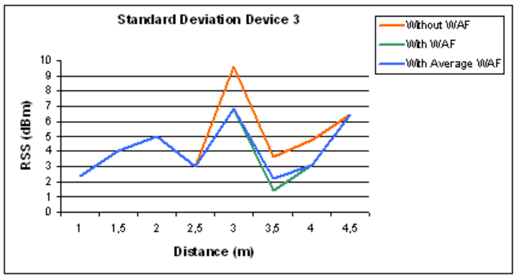

Fig. 15. Standard Deviation of the collected RSS values for device 3

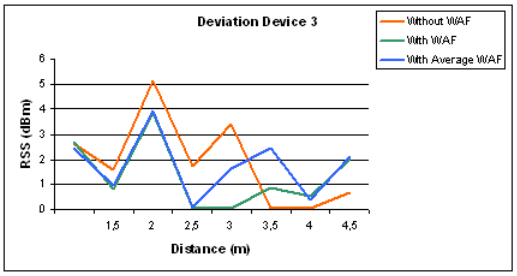

Fig. 16. Deviation between the collected RSS values and theoretical model for device 3

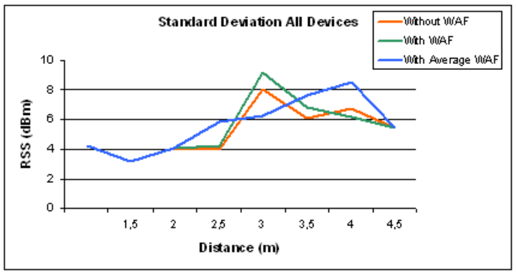

Fig. 17. Standard Deviation of the collected RSS values for all devices

VII. CONCLUSION

This paper describes a location system for persons and objects in an indoor environment, using ZigBee technology.

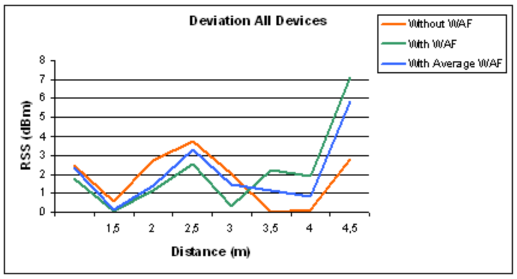

Fig. 18. Deviation between the collected RSS values and theoretical model for all devices

ZigBee nodes can function as RFID tags, having each one a unique EPC identification number. Sensors can be associated with the Zigbee wireless nodes to create applications for home, health and traffic control.

Location is determined, using a propagation model, based on the WAF model, together with a triangulation algorithm. Tests demonstrate an increase in accuracy when the WAF parameter is used in the propagation model. Even the use of an average value for WAF or a set of values proved to be effective. The same equation parameters can be used for each fixed device, avoiding the need to collect RSS values for each fixed device. This becomes very important when a new location system is to be installed in a new environment, where the building architecture is similar.

It is important to remark that signal characterization is crucial to ensure a good performance by the propagation model. The more values of RSS are collected the more accurate the model becomes. On the other hand, it can be demonstrated that with a relative small number of collected values it is possible to develop an effective flexible system, with errors from 2.5 to 0.25 meters when using the developed propagation model.

Results also show that in the moment that the location is initiated, it is important to collect several RSS values in order to obtain an average RSS value in that time interval. The wide range of values that can be collected in the same position can vary enough to generate significant errors. This variation is due to multipath that as the tendency to increase with distance. The closer the devices are of each other the more easily can the propagation model be characterised. This fact proves that the adopted concept of using a small set of location environments that together make a bigger environment, is a valid option. This concept is especially interesting in a ZigBee using system, being that these networks can have thousands of devices associated to them, reducing the distances between the devices, all this at a low cost and low energy consumption.

A more advanced system would be able to track the mobile device instantaneously. The system could be controlled by a central server that managed the ZigBee network and processed all the information needed to the location algorithm. In a future system it would be possible to obtain not only a EPC identification number but a wide range of information regarding the location environment.

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