RFID System with ZigBee Technology

Gomes Gonçalo
Instituto Superior Técnico
Lisbon, Portugal
Email: gon.ls.gm@gmail.com

Abstract—This work intended to maximize the advantages existing in the use of RFID technology with ZigBee, with the purpose of developing an indoor location system. The main requirements of the system are the creation of a WSN (Wireless Sensor Network), in which each device operates like RFID tags, and the development of a location algorithm. To accomplish that, location systems are studied, with more emphasis the indoor location systems, in order to develop a location algorithm.

The developed location algorithm uses a propagation model based on the wall attenuation factor propagation model (WAF) together with a triangulation algorithm. A variety of tests was carried off in an indoor environment in order to analyse in detail the developed propagation model. The achieved results show that the developed location system is viable showing itself to be effective, flexible and easily adaptable to various locations. It is also proved that the use of a ZigBee network is ideal in this location system.

I. INTRODUCTION

A. Motivation

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 this area. As an example we have the RFID (Radio Frequency Identification) technology, which revealed a huge potential in a variety of areas.

Given its potential it’s being used in areas such as: health, national security, sensor networks, location systems, etc [1]. 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.

Lately, there has been a growing interest in the integration of RFID and WSN (Wireless Sensor Network) systems. More and more often new generations of RFID tags include sensors, as well as more WSN that require automatic identification mechanisms [3]. A fusion of RFID and WSN technologies can originate the development of a variety of applications, particularly in terms of location, in residential environments, corporate environments and critical infrastructures worldwide [3].

The use of RFID technology with ZigBee protocol provides the study of effective, low energy consumption, and financially accessible location systems. The challenges of these location systems are the characterization of the location scenarios through radio signals, in order to make them adaptable and reliable in any environment.

B. Objectives

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.

With the objectives in mind, it’s necessary to assemble a ZigBee network in an indoor environment, develop software that applies the chosen location method and perform tests to show that the project is feasible.

II. TECHNOLOGICAL FRAMEWORK

For a better understanding of the work some of technical characteristics of both used technologies are described. A description of the capabilities and characteristics of RFID and ZigBee will allow the understanding and of the advantages and also the reasons why both technologies can be used in an indoor location system.

A. RFID

The origin of RFID technology can be found in works that go back to the beginning of the XX century and since then the evolution of RFID hasn’t stop [4]. Nowadays there are many options in the field of automatic identification of people and objects, as is the case of bar codes, biometric identification, voice identification and optical character recognition (OCR). The advantage of RFID is allowing the automatic identification of people and objects at considerable distances through radio waves.
1) **RFID system components and characteristics**: In its simpler form, an RFID system is composed by a RF (Radio Frequency) reader and a RF tag (transponder), allowing the identification of people or objects. When a reader detects in his neighbourhood or coverage area a tag it will initiate a communication protocol with the tag through RF signals and collect the information existing in the tag.

RFID tags can be divided in three different groups: passive, semi-passive and active. The Auto-ID Centre classification [5], in Fig. 1, considers five tag classes defined accordance with their functionality. Classes 1 and 2 are passive, class 3 is semi-passive and classes 4 and 5 are active.

![Class structure Auto-ID Center RFID tags](image)

A passive tag is made out of a small integrated circuit and an antenna capable of transmitting and receiving RF signals, also existing in semi-passive and active tags a source of energy. The tags circuit stores information, such as the identification number and can also have processing capabilities.

a) **Memory**: An RFID tag is of the following types: WORM (Write Once Read Many), RW (read/write) and mixed. In WORM type tags the information regarding the tag identification number is permanently saved in the memory. In RW tags this number can be altered or substituted by other information. In mixed tags although the identification number can’t be altered there is RW memory for data storage that can be written and changed. Passive tags typically have a non-volatile memory that can go from 64 bits to 1kbyte while active tags normally have bigger memories that go from 16 bytes to 128 kilobytes [6].

2) **Electronic Product Code (EPC)**: One of the developments that contributed to the success of RFID was the creation of EPC (Electronic Product Code). The EPC is the unique identification number of the RFID tag that is saved in the memory. It’s similar to the UPC (Universal Product Code), but besides providing identification to the producer and the product allows the identification of the actual product. The codification system designed by the Auto-ID Centre consists of a 96 bits code word with the structure shown in Fig.2.

![EPC-96 TYPE I](image)

The code Header has 8 bits and indicates the EPC length. The EPC can go from 64 to 256 bits. In Fig.2, the ‘01’ indicates that it’s a type 1 EPC. The type 1 EPC has 96 bits. The second field (EPC Manager) contains the number that identifies the manufacture of the product. In a 96 bits code, are used in this field 28 bits that allow the generation of 268 million \(2^{28}\) manufacture unique identifiers. In the field of Object Class the type of product is identified. In a 96 bits code, each manufacture can have 16 million product classes. The Serial Number, with 36 bits, can generate 68 billion \(2^{36}\) numbers of identification.

B. **ZigBee Technology**

The use of networks in communication systems is becoming day by day a necessity. In technologies such as ZigBee wireless networks, WPANs (Wireless Personal Area Networks) are used. WPANs are destined to the space around a person or object with a range of about 10 meters in every direction. The main goals of these wireless networks are the low cost, low energy consumption, short range and reduced size.

The workgroup IEEE 802.15 is responsible for the definition of the rules to be used in WPANs. This workgroup defined three classes of WPANs classified in accordance with bit rate, energy consumption and quality of service (QoS). Low rate networks IEEE 802.15.4/LR-WPAN (Low Rate Wireless Personal Area Network), allow the development of a set of industrial applications, residential and medical among others that have a low energy consumption.

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. It was developed in 2002 and denies the network and application layers and the security service between them. ZigBee using devices shall have a maximum range of 150 meters, depending this value of the environment and energy consumption of the using application. They operate in non-licensed frequencies on the ISM (Industrial, Scientific and Medical) band (2.4 GHz global, 915 MHz Americas and 868 MHz Europe). The bit rates for the different frequencies are: 250 Kbps at 2.4 GHz, 40 Kbps at 915 MHz and 20 Kbps at 868 MHz.

1) **The IEEE 802.25.4 Standard**: This standard defines two types of devices: FFD (Full Function Device) and RFD (Reduced Function Device). An FFD device works in any network topology, performing the function of network coordinator and has access to all other devices. An RFD device is limited to a configuration of star topology, not being able to function as network coordinator. An RFD can only communicate with FFD device and is only associated to one FFD at a time. It’s destined to be used in applications that require low energy consumption.
a) **Network Topologies:** The IEEE 802.15.4 standard defines three types of network topologies: star topology, peer-to-peer topology and mesh network [8], [9]. Fig.3 shows the three topologies.

![Network Topology Diagram](image)

The star topologies require at least one FFD device functioning as network (PAN) coordinator, being the remaining FFD. The communication is established between devices and the network coordinator. The PAN coordinator is normally powered by the electric network and the remaining devices (FFD or RFD) by batteries.

In peer-to-peer topologies there also exists a PAN coordinator, being that in this topology all the devices can communicate with each other. This 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. Any of the FFD devices can work as coordinator and provide monitoring services to other devices.

b) **Layers:** The IEEE 802.15.4 standard defines two layers (low level): the physical layer (PHY) and the media access control layer (MAC).

The physical layer (PHY) as the goal of accommodating the low cost interfaces needs allowing high levels of integration. This layer provides two services: the PHY data service and the PHY interface control service for the physical layer management entity (PLME). The functions of the PHY layer go from activation and deactivation of the radio signals transmitter/receiver, energy detection (ED), link quality indication (LQI), channel selection, clear channel assessment and transmission and reception of packages.

The functions of the MAC layer go from beacons management, channel access, GTS management, frame validation, frame delivery recognition, association and dissociation of devices. This layer provides two services: the MAC information service and the MAC management service. The MAC information service allows the transmission and reception of MAC protocol data units (MPDU), through the PHY information service. The MAC management service, if the device is a PAN coordinator, manages the network beacons.

2) **ZigBee:** The ZigBee technology became available to the public in June 2005. This technology has as support the PHY and MAC layers of the IEEE 802.15.4 standard, defining the network and application layers. The ZigBee architecture, shown in Fig.4, is based on the OSI (Open Systems Interconnection) model of seven layers, but only defines the more relevant layers in order to obtain the needed functionalities.

![ZigBee Architecture Diagram](image)

The network layer (NWK) has mechanisms with functionalities of management and security, routing and association and dissociation of devices in a network. The network layer coordinator is responsible for the initiation of new networks whenever necessary and for the attribution of addresses to new devices.

The application layer is composed by the application support sublayer (APS), framework of applications (AF), ZigBee device object (ZDO) and by the application objects [8].

a) **ZigBee Devices:** ZigBee distinguishes the concept of physical devices (FFD, RFD) using the notion of logical devices. The ZigBee Coordinator is the first type of logical device, assuming a role much similar to a coordinator in the IEEE 802.25.4 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 [9].

### III. Location Systems

The success using the GPS system in monitoring and location of objects in outdoor environments encouraged the application of the same techniques to indoor environments. Unfortunately these techniques don’t constitute a valid option in indoor location [10]. Given these difficulties, there has been a growing interest in location techniques motivating allot of research in the area that has resulted in many solution to the problem. The many and different techniques existing nowadays can be very confusing, in order to avoid confusion the Hightower and Boriello [11] taxonomy is recommended.

A. **Indoor Location Systems**

This work is centred in the development of an indoor location system, for this reason some of the more relevant existing systems are going to be described. The Hightower and Boriello [11] taxonomy presents various indoor location techniques like scenario analysis (Location Fingerprint [12], [13]), but the idea of this project is to use indoor propagation models.
B. Indoor Propagation Models

The propagation of electromagnetic waves in indoor environments, especially in a building interior, is characterised by wave reflections, diffractions and dispersion in the internal structures. The transmitted signals arrive to the receptor through many paths originating fluctuations in the received signal. This effect is called multipath propagation and it’s affected by the materials used in the obstruction of the building and by the surrounding objects, which makes it very difficult to predict the received strength. To eliminate this problem propagation models are used to relate the received power with the distance between transmitter and receiver. Some of the more relevant propagation models like, the Rayleigh Fading Model [14] or the Rician Distribution Model [15] are widely known but they have some disadvantages. Two propagation models, that show to be promising, are now presented.

1) Wall Attenuation Factor Model (WAF): The wall attenuation factor model (WAF) is quite attractive given its ability to describe the slow fading phenomenon and the attenuation that these types of environments introduce in the signal propagation. It uses the attenuation factor that allows predicting the behaviour of the signal when it propagates through environments where walls constitute the main obstacle (indoor environments). This model derives from the floor attenuation model (FAF) [16] in which the attenuation factor introduces a term that accounts that thickness. In equation 3, \( L_0 \) refers to the attenuation of a reference wall with a thickness of \( e_0 \), being \( k_i \) the number of walls of type \( i \) with a thickness \( e_i \). The adjusted term substitutes, \( i \) in equation 2, the term \( \sum_{i=1}^{N} k_i L_{w_i} \) in order to account for the thickness of the walls originating equation 4.

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

The adjusted Motley-Keenan model evaluates the thickness of the walls on the attenuation factor introducing a term that accounts that thickness. In equation 3, \( L_0 \) refers to the attenuation of a reference wall with a thickness of \( e_0 \), being \( k_i \) the number of walls of type \( i \) with a thickness \( e_i \). The adjusted term substitutes, \( i \) in equation 2, the term \( \sum_{i=1}^{N} k_i L_{w_i} \) in order to account for the thickness of the walls originating equation 4.

\[
\text{AdjustedTerm} = \sum_{i=1}^{N} k_i L_{0i} \log_3(\frac{e_i}{e_0}) \quad (3)
\]

\[
\text{PL}(d)_{[dB]} = PL_{d[dB]} + 10n \log(d) + \sum_{i=1}^{N} k_i L_{0i} \log_3(\frac{e_i}{e_0}) \quad (4)
\]

IV. DEVELOPED SYSTEM

The developed system created 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 predefined positions. The several devices also function as RFID tags, having each one a unique EPC identification number. 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 Requirements and Implementation

In order to develop a prototype of this system it was necessary the use of ZigBee devices that could function has RFID tags automatically identify of the fixed devices and the mobile device. The system required support devices (ZigBee Boards) for the ZigBee devices. To locate the mobile device it was used an indoor location algorithm. The implementation of the location system implied the purchase of the ZigBee modules and with the help of an existing project PCBs (Printed Circuit Boards) were made to serve as support devices. In the implementation of the system it was also necessary to develop software in order to generate and initialise the WSN, to establish communication with the ZigBee devices and also to use the location algorithm.

B. System Prototype

Five ZigBee devices compose the developed system prototype, the four devices that are in fixed positions are RFDs, programmed as ZigBee End Devices. Each one of these modules is assembled in a ZigBee board to assure that the device is powered. The fifth device is mobile, composed by a ZigBee module also assembled in a ZigBee board and connected to a portable PC trough an RS-232 interface. The mobile device
is FFD and it’s programmed as a ZigBee Coordinator. The four RFD devices can also be called BS (Base Station) and the mobile as MS (Mobile Station).

Each one of these four RFD fixed devices works independently being powered by batteries. These devices are in sleep mode becoming active whenever they detect the mobile device. When the mobile device starts functioning it starts transmitting a signal so that the RFD devices can detect him.

The mobile device supplies the portable PC with data relative to the RSS values detected through the communication with the fixed devices, so that the PC can start processing the location algorithm and yield a possible location for the mobile device.

C. Location Algorithm

One of the objectives of this project is to develop a reliable location system that presents acceptable results allowing to estimate the location of a person or object. For that it is necessary to develop a location algorithm.

The developed location algorithm can be divided in two steps. In the first step a propagation model is used to calculate the distances between the fixed devices and the mobile device, that is achieved through the values of received signal strength (RSS) given by the mobile device. In the second step knowing the distances calculated by the propagation model it is possible to determine a possible location for the mobile device using a triangulation algorithm.

In order to initiate the first step of the algorithm it’s necessary to determine the parameters of the propagation models equation. These parameters are found through the previous collecting of RSS values, so it can be possible to obtain a characterisation of the location environment in terms of RF signals. This previous stage is much like the off-line phase used in scenario analysis methods.

D. Propagation Model

The used propagation model is based on the wall attenuation factor (WAF) propagation model. The used model uses equation 1 but making the WAF parameter equal to zero (equation 5). In this model the attenuation introduced by a wall is accounted for in the previous stage (off-line).

During the collect of RSS values, to obtain a characterisation of the location environment through the parameters n and \( P(d_0) \) in equation 5, the values that are affected by the presence of a wall are identified. 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 characterisation of the RF signal in the location environment.

The option made to use equation 5 instead of equation 1 is due to the fact that not always the walls constitute an obstacle between the mobile and the fixed devices. Let’s imagine a radius of a given distance around a fixed device, it’s possible that the obstructions due to the presence of walls don’t always exist throughout all circumference. The obstructions can exist in a certain direction and stop existing in other directions.

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

E. Triangulation Algorithm

In the location system the data that shows the location of the mobile device has to relative to known positions, the mobile device has to be found in a specific environment that allows the data relative to his location to be easily identified. For that it’s necessary to define a coordinates system in the location environment (Fig.6). The coordinates system used is a 2D system, that assumes that all devices are at the same height. After defining the coordinates system the locations for the fixed devices are chosen so that they can cover all of the location area, being set \((x, y)\) coordinates for each device. Having the positions of at least three fixed devices and their distances to the mobile device it’s possible to calculate a set of coordinates \((x, y)\) for the mobile device, determining his position. In order to do that it’s used a triangulation algorithm to be executed by the portable PC after calculating the distances.

The used algorithm was the Dynamic Triangular Algorithm (DTN) [19]. This algorithm was chosen because of the small error (maximum of 2 meters) that he introduces, in a reduced area location environment much like the one where our system
was tested. Another characteristic that favours the DTN is his low complexity not requiring allot of time for processing.

V. RESULTS

For testing, the system was installed in a residential environment in order to test if the system was effective in a very differentiated indoor environment which makes the characterisation of the RF signals much more difficult.

A. Testing Environment

In this testing scenario, the four fixed devices were placed in pre-defined positions in order have a regular location space. The chosen location space is shown in Fig. 7.

Table 1 shows the coordinates for each fixed device in a 2D referencial with EB1 being the origin of the referential.

<table>
<thead>
<tr>
<th>Fixed Devices</th>
<th>Coordinates (x,y) in meters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device 1</td>
<td>(0,0)</td>
</tr>
<tr>
<td>Device 2</td>
<td>(4,5,3,8)</td>
</tr>
<tr>
<td>Device 3</td>
<td>(8,5)</td>
</tr>
<tr>
<td>Device 4</td>
<td>(3,7,9)</td>
</tr>
</tbody>
</table>

TABLE I

FIXED DEVICES COORDINATES

The reduced dimensions of the chosen location area to test the prototype are due to the fact that the ZigBee modules have a small range in indoor environments with many obstacles and also because of the possibility that the error in the mobile device increases with the distance between fixed and mobile devices.

In ZigBee using system, a technology that has expects a low energy consumption, to be low cost and that has the capability of having a vary large number of devices associated to the same network, it’s very important to use those advantages. With that in mind the purposed system uses small areas of location that in their whole define a much bigger location area (Fig.8). This concept needs a high number of fixed devices then those used in the prototype, but it minimizes the error in location, allows the small areas to be very similar and with much less obstruction and therefore much easier to characterize.

B. Tests

To characterize the propagation of the signals in the chosen location area it was necessary the collection of RSS values from the fixed devices at different distances from the mobile device. The collection of RSS values was made in three fixed devices and in three different directions for each device. With these values it was possible to determine the parameters for the propagation model.

In order to evaluate to capacities and reliability of the location system three types of different tests were made: location without the introduction of the WAF factor, location with the introduction of the WAF factor and location with the introduction of a average WAF factor.

The characterisation of RF signals is essential to the location system, only doing this it’s possible to predict the signal behaviour during propagation. This characterisation is made through the collection of RSS values in a previous location stage (off-line). This procedure isn’t new and it’s used in scenario analysis (Location Fingerprint).

1) Parameter of attenuation WAF: In order to calculate the WAF value tests were made where the mobile device is placed at several distances from the fixed device to collect RSS values. After that the same procedure is made but now with the presence of a wall between the devices. Table 2 shows the values that were calculated.

<table>
<thead>
<tr>
<th>Distance (meters)</th>
<th>Device 1</th>
<th>Device 2</th>
<th>Device 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>-</td>
<td>4.23 dB</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>4.42 dB</td>
<td>11.5 dB</td>
<td>13.67 dB</td>
</tr>
<tr>
<td>3.5</td>
<td>17.42 dB</td>
<td>-</td>
<td>6.5 dB</td>
</tr>
<tr>
<td>4</td>
<td>18.08 dB</td>
<td>8.83 dB</td>
<td>-</td>
</tr>
</tbody>
</table>

TABLE II

WAF PARAMETERS

Table 3 shows the average value of WAF for each fixed device and for the set of values of all devices together.

2) Characterisation of RF signals without WAF: In this stage the RSS values were collected from each fixed device and in all three different directions. The value for the attenuation rate and the received signal strength at the distance of 1 meter were calculated through logarithmic regression of the
RSS values.

The graphic on Fig.9 shows logarithmic regression of the RSS values collected for the fixed device 3, and table 3 shows the parameters calculated for all fixed devices and for the set of values of all devices together.

![Fig. 9. Collected values for device 3](image)

**Fig. 9. Collected values for device 3**

<table>
<thead>
<tr>
<th>Device</th>
<th>Average WAF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device 1</td>
<td>10.92 dB</td>
</tr>
<tr>
<td>Device 2</td>
<td>11.28 dB</td>
</tr>
<tr>
<td>Device 3</td>
<td>9.67 dB</td>
</tr>
<tr>
<td>All Devices</td>
<td>10.58 dB</td>
</tr>
</tbody>
</table>

**TABLE III**

**AVERAGE WAF PARAMETERS**

With the calculated values in the tested situation it was possible to plot the caracteristique 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 (Fig.10 and 11) compare the theoretical model with the average of the collected RSS values at different distances.

![Fig. 10. Average Collected Values VS. Theoretical Model](image)

**Fig. 10. Average Collected Values VS. Theoretical Model**

<table>
<thead>
<tr>
<th>Device</th>
<th>Attenuation Factor (n)</th>
<th>RSS at 1m ((P(d_0)))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device 1</td>
<td>2.382</td>
<td>-45.50 dBm</td>
</tr>
<tr>
<td>Device 2</td>
<td>3.637</td>
<td>-40.32 dBm</td>
</tr>
<tr>
<td>Device 3</td>
<td>2.806</td>
<td>-48.08 dBm</td>
</tr>
<tr>
<td>All Devices</td>
<td>3.027</td>
<td>-44.50 dBm</td>
</tr>
</tbody>
</table>

**TABLE IV**

**CALCULATED PARAMETERS WITHOUT WAF**

With WAF collected RSS values, but with the difference that the WAF value is now taken into account. Table V shows the calculated values of the parameters through logarithmic regression and Fig. 12 and 13 show the graphics that compare the theoretical model with the average of the collected RSS values at different distances.

![Fig. 11. Average Collected Values VS. Theoretical Model](image)

**Fig. 11. Average Collected Values VS. Theoretical Model**

<table>
<thead>
<tr>
<th>With WAF</th>
<th>Attenuation Factor (n)</th>
<th>RSS at 1m ((P(d_0)))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device 1</td>
<td>2.512</td>
<td>-45.77 dBm</td>
</tr>
<tr>
<td>Device 2</td>
<td>2.803</td>
<td>-41.12 dBm</td>
</tr>
<tr>
<td>Device 3</td>
<td>2.391</td>
<td>-48.07 dBm</td>
</tr>
<tr>
<td>All Devices</td>
<td>2.255</td>
<td>-45.21 dBm</td>
</tr>
</tbody>
</table>

**TABLE V**

**CALCULATED PARAMETERS WITH WAF**

3) **Characterisation of RF signals with WAF**: This characterisation is very similar to the first one and uses the same...
4) Characterisation of RF signals with average WAF factor: This characterisation is very similar to the first two and uses the same collected RSS values, but with the difference that the same value (average WAF) is now taken into account. The WAF parameter was once again introduced in the positions that had no NLoS (Non-Line-of-Sight), being the values the ones presented on table VI. In these conditions the table () shows the calculated values of the parameters through logarithmic regression and Fig. 14 and 15 show the graphics that compare the theoretical model with the average of the collected RSS values at different distances.

<table>
<thead>
<tr>
<th>With WAF</th>
<th>Attenuation Factor (n)</th>
<th>RSS at 1m ($P(d_0)$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device 1</td>
<td>1.393</td>
<td>-46.90 dBm</td>
</tr>
<tr>
<td>Device 2</td>
<td>2.942</td>
<td>-40.59 dBm</td>
</tr>
<tr>
<td>Device 3</td>
<td>2.350</td>
<td>-48.27 dBm</td>
</tr>
<tr>
<td>All Devices</td>
<td>2.537</td>
<td>-44.64 dBm</td>
</tr>
</tbody>
</table>

TABLE VI
CALCULATED PARAMETERS WITH AVERAGE WAF

During the characterisations the propagation model parameters were calculated for each device individually and for the set of values of all devices together. Being calculated the parameters for each device it’s obtained a specific equation for that device. Calculating the model parameters for the set of values of all devices together it’s obtained an equation that can be used on all devices.

C. Location Results

After the characterisations 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.

D. Errors and Deviations

To better evaluate the capability of the propagation model to be effective and reliable the standard deviations of the collected RSS values and the error that those deviations introduce in the location were calculated. The presented results are relative to the fixed device 3 and for the set of values of all devices together.

Fig. 13. Average Collected Values VS. Theoretical Model

Fig. 14. Average Collected Values VS. Theoretical Model

Fig. 15. Average Collected Values VS. Theoretical Model

Fig. 16. Standard Deviation of the collected RSS values for device 3

Fig. 17. Deviation of the collected RSS values for device 3
E. Result Analysis

Analysing the graphics comparing the average of RSS values collected with the theoretical model, it’s possible to observe that in certain locations the introduction of the WAF parameter increased the error but in general the theoretical model was approximated to the average of RSS values collected, decreasing the peaks where the errors were bigger. This fact can also be proved through the graphics relative to the deviations, where it can be seen a decrease in RSS values (which translates into a decrease in error) when the WAF parameter is introduced. This decreased is also noticed when using the average WAF parameter.

It’s 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. It’s also verified that when the set of values of all devices together is used to calculate the model parameters it doesn’t produce very different results of those presented when each fixed device has its own equation.

VI. Conclusions

This work was purposed with the objective of developing a RFID system with ZigBee technology that worked as a location system for persons and objects in an indoor environment. The project focused on the development of a location system using a ZigBee network. The choice for the location method to be used in the system consisted in the use of a propagation model together with a triangulation algorithm.

After choosing a propagation model based on the wall attenuation factor (WAF) propagation model, the location system was developed using a ZigBee network. In order to prove that ZigBee networks are ideal in these kinds of location systems, that are based on propagation models some tests were made.

These tests focused on the propagation model being tested several variations of the model. The results proved that the use of WAF parameter in the propagation model increased the models accuracy. As long as introduced with some criteria and in needed locations. Even when the average WAF value is used instead, the propagation model proved to be effective.

Another important aspect is due to the results presented when the model is characterised by the set of values of all devices together. The results shown to be very acceptable making the developed system more flexible. Taking the same equation in every fixed device the characterisation stage becomes simpler, not having the need to collect RSS values specific to each fixed device. These characteristics become very important when in an indoor environment where a location system is to be installed, the building architecture is all very similar. Let’s take the example of an office building where all the divisions are very similar, it’s then possible to make the characterisation of one division only, using the calculated parameters for that the division in the rest of the building.

It’s important to notice that the characterisation of the signals is crucial in order to ensure a good performance by the propagation model. The more values of RSS that are collected for characterisation the more accurate the model becomes. On the other hand it can be shown that with a relative small number of collected values (comparing with scenario analysis methods) it’s possible to develop an effective flexible system, with errors from 2.5 to 0.25 meters when using the developed propagation model.

The results also show that in the moment that the location is initiated, it’s 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 specially 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.

REFERENCES


