ACTA SCIENTIFIC MEDICAL SCIENCES

Volume 2 Issue 7 October 2018

Research Article

Real Time Location Systems Adoption in Hospitals - A Review and A Case Study for Locating Assets

Sara Paiva[1]*, Diogo Brito[2] and Lionel Leiva-Marcon[3]

[1]ARC4Digit - Applied Research Centre for Digital Transformation, Polytechnic Institute of Viana do Castelo, Portugal

[2]Polytechnic Institute of Viana do Castelo, Portugal

[3]Proactive Swiss, Route de Saint - Cergue 303, Nyon, Swiss

***Corresponding Author:** Sara Paiva, ARC4Digit - Applied Research Centre for Digital Transformation, Polytechnic Institute of Viana do Castelo, Portugal.

Received: August 27, 2018; **Published:** September 10, 2018

Abstract

Real time location systems (RTLS) can assume a big relevance in a hospital environment. Plenty of studies have been reported at this respect and we start by providing a literature review on some of them, so it is clearer to the reader the variety of scenarios RTLSs can be applied to in a hospital environment as well as benefits they might have. As main contribution of this work, we introduce our own proposal of a RTLS in a hospital environment with the main goal to provide technicians the possibility to quickly find for a given equipment, through a website in a desktop computer we assume to exist in each floor. This particular proposal started from the need to find urgent equipment, such as a reanimation machine, that can represent a life or death situation. We introduce the components of the architecture, that mainly rely on beacons and Raspberry Pies. We detail implementation aspects and present the evaluation of the system in three main scenarios we foresee as a potential problem that could exist in a real scenario because of the beacon signal interference: placement of raspberry pie's, materials of buildings and signals from other equipment. The main conclusion is that the system is totally adequate for non-visit moments and in buildings not made of concrete high thickness. For the rest of the situations, we provided recommendations regarding the placement of receptors.

Keywords: Real-Time Location Systems; Indoor Tracking; Assets Tracking and Monitoring; Healthcare Improvement

Introduction

Real-time location systems (RTLS) are becoming much more used since wireless technologies started to provide the necessary infrastructure to develop useful services. RTLS refers to a general area of technology that allows to determine the current position of an object based on real-time information gathered through a wireless system of some sort [1]. When speaking about RTLS systems, we mainly can have two perspectives systems are built upon: server-based and client-based RTLS systems. And they mainly differ on whether the object being located is moving or standing still. The global positioning system (GPS) was one of the first well-known cases of RTLS to track vehicles but currently we assist this technology being used in outdoor environment in several scenarios such as logistics applications, transportation management or land-based transports. In this case - client-based system - the positioning of the device is made directly on the device and usually uses an app which analyzes the signals of Wi-Fi access points, LED and/or beacons and usually also contains a database with which the signal strength is matched. Asset tracking depend of its nature and location. Indoor environment changes radically the technologies that can be used and almost excludes GPS and cellular based systems due to their lack of signal. In these situations, other technologies arise such as Radio-frequency identification (RFID), Wi-Fi or, more recently, Bluetooth Low Energy (BLE) technology. Some existent scenarios that use some of these technologies include equipment tracking, real time personnel finding, patient and guest finding [2], among others. Some of these scenarios represent typical server-based RTLS scenarios that is characterized by a Wi-Fi enabled device, a tag or a Bluetooth beacon sending out a unique key that is captured by a specific hardware that transmits it to a server that calculates positioning using a specific algorithm or techniques. Server-based scenarios are totally adequate and currently very used for asset tracking in hospitals. In Brito [3] we presented a server-based architecture positioning system using BLE precisely for tracking assets in hospitals. This paper is an extension of our previous work and it contains a more detailed related work section regarding RTLS in hospital environments, in order to meet the readers of this journal. The technological description of the solution is also more detailed.

The rest of this paper is organized as follows: in the next section we refer to real time location systems, technologies used and also several cases of application in hospital environments and the benefits of its adoption. Next, we present our solution starting with an overview of the main goals we wish to achieve and then explaining the components that make part of the architecture. We explain the algorithms used to calculate equipment coordinates, considering three main scenarios we identified. Next, we present experimentation tests regarding possible situations that could lead to signal blocking namely with the interference materials have. Finally, we present discussion and conclusions of our work.

Real Time Locations Systems (RTLS)

Real-Time Location Systems are used to automatically identify and track the location of equipment or people in real time [4]. It uses a combination of hardware and software to produce a global system that allows businesses to provide end services to their clients with a variety of different applications. In the next sections, we will introduce some of the technologies RTLS typically uses, refer to the architecture usually behind RTLS systems and go deeper into the applications and how RTLS are being used in hospitals.

Technologies

Technologies and system concepts used to create a RTLS are several [5]: Active radio frequency identification (Active RFID), Active radio frequency identification, Infrared (IR), Optical locating, Low-frequency signpost identification, Semi-active radio frequency identification (semi-active RFID), Passive RFID RTLS locating via Steerable Phased Array Antennae, Radio beacon, Ultrasound Identification (US-ID), Ultrasonic ranging (US-RTLS), Ultra-wideband (UWB), Wide-over-narrow band, Wireless Local Area Network (WLAN, Wi-Fi), Bluetooth, Clustering in noisy ambience or Bivalent systems. We will refer next to the most important ones regarding the proposal this paper presents. RFID was one of the first technologies that started to be used to make RTLSs. It is a technology that uses electromagnetic fields to identify and track objects. A typical RFID system works with three elements: a scanning antenna, a transceiver and the RFID tag. The antenna scans for tags, and when the tag detects the activation signal, send the information. The RFID technology is more used to simulate bar codes and can be used to track several things such as materials or even animals (and maybe one day humans). This technology is not the best for indoor location because it doesn't give us a precise location of the tag, it can only say where the object is in an area. In addition, there are some considerable costs associated when configuring a system because a lot of antennas are required. Bluetooth Low Energy (BLE) equipment is now in several scenarios replacing RFID, as its evolution. Known also as Bluetooth Smart, it was introduced in 2006 by Nokia under the name of Wibree and merged in 2010 with Bluetooth 4.0 and get the name has we know it today. Beacons are an extension of the BLE technology. In difference with conventional Bluetooth, BLE broadcasts much smaller packets of data and can operate on a logic board with a coin battery on it and it's very cheap to produce or buy. Nowadays, depending on which beacons we use, we can choose between packets to broadcast the data: iBeacon and Eddystone. Although they are almost the same because both broadcasts the same information, the Eddystone packets have an advantage: a telemetry packet is broadcasted too that can give us some additional information, such as the battery voltage or the temperature. Wi-Fi can also be used for the purpose of indoor location because it is present in almost every place. However, it can represent an elevate cost considering the necessity of having a big number of routers; it is not easy to get a precise indoor location; adding, removing or simply changing the location of a router/AP has a direct impact on the RSSI map. Bluetooth falls in the scope of wireless technologies to exchange data over short distances. It can be adequate to transmit information from moving assets with RFID or BLE to, for example a Raspberry PI (RP) placed strategically. A RP is no more than a small computer that has the ability to receive data through Bluetooth (and other technologies) and communicate it to a central server for further processing.

RTLS in Hospitals

The growth of the health service as well as the need for medical care means that the health units are continually challenged to provide better service to patients, and quality and safety are important parameters. RTLS appear in this context as a way to ensure safety and security to patients and, in the end, to the entire health unit as a whole. Health units have long realized that technologies such as RFID or, more recently, RTLS systems can help the organization to identify, locate, monitor patients, visitors, physicians, auxiliaries, equipment and objects [5,6]. A questionnaire study carried out with 81 health operation directors showed they feel RTLS can have clear benefits in a hospital and in an improved functionality of the hospital's departments [7]. Overcrowding of emergency departments (ED) is another benefit pointed out in Jochem [8] for the use of RTLS in hospitals. The most severe effect of overcrowding in ED is an increased mortality rate. Other effects include increased severity of medical errors, prolonged length of stay in the hospital, and delayed time-critical interventions. Ohashi defend that the use of a RTLS in a hospital can increase hospital workflow and efficiency [9], through the use of a workflow analysis framework and detection of inefficient routes in ED from by medical staff made possible by the use of a bracelet or tag that registers movements inside ED [10]. Although with an enormous potential and benefits, the use of RTLS in hospitals is not yet very common. In 2012, only an estimated 15% of North American health facilities adopted RTLS techniques and systems. The acceptance of health workers and their interconnection with the RTLS is fundamental for its success [11]. A key role for this acceptance can be played by RTLS vendors [12]. Regarding known implementation, literature mentions some cases [10]. One of the first reported use of RTLS with RFID technology was described in Janz., *et al.* [13] with the purpose to exam the usefulness of the technology in a Level-1 trauma unit. Results shown that RFID technology can assist in the measurement and control of workflow processes. Another case study during 2016 addresses the challenge to incorporate RFID into medical practice [14]. They conducted a case study - entitled Location-based Medicare Service project - that demonstrated RFID integration into the medical world at one Taiwan hospital and aimed at containing SARS, a dangerous disease that struck Taiwan in 2003. As part of the project, patients were tracked, and their temperature was measured by an RTLS, which allowed to reduce the work of staff and free them to another tasks. Also, visitors and medical staff were tracked in the hospital to reduce contact time with infected patients, in order to reduce the risk of contamination. In this case, considering the clear benefits RTLS had to all involved, it was very well accepted. The use of a RTLS to help hospitals execute a coordinated response during a disaster is reported in Souza., *et al.* [15], where authors also enhance the importance of considering the several existent technologies and the associated benefits, drawbacks, and challenges, before implementing a RTLS in a hospital environment. Shirehjini., et al. present a robust system for position and orientation determination of equipment that uses RFID mounted on flooring plates and several peripherals for sensor data interpretation [16]. Another example of RTLS applied to hospitals is presented in Nibbelink [6] in a case using RFID and RTLS and authors points out as main benefits the following aspects: patient and staff safety (by preventing patient elopement through integration with access control, video surveillance, and other electronic security and building technology), hospital efficiency (reduced time and costs spent in locating assets, equipment, patients, and staff), hospital finance (with RFID and RTLS, organizations experience less theft), patient satisfaction (providing the very best in care and customer service to the patients, visitors, and staff improves patient experience and outcome). A RTLS was also been reported to being used to record events according to patient locations in the service with enough details to precisely build a process using a Process Mining tool [17]. An experiment was made in a OR environment with BLE tags to see if they are reliably tracked and detected. Some detected problems reported in the study include inactivity of the tag and random changes into other nearby rooms because of multipath effects [18]. Another example is the Florida Hospital that implemented a RTLS system for two main purposes: event alerts and customer satisfaction [19]. In the first case, RTLS contributes to adding context to the patient's pathway, trending and predictive modeling, actionable data at the right time to the right person. For customers, it provides real time access, information and flow - engagement in care process, alerts for wait states, knowledge of their progress in their care. Another usage of RTLS in hospitals addresses the overcrowding of ED [8] and refer the RTLS might offer a solution for this problem by gathering information about the workflow of hospital staff. Other similar contributions exist to manage patients at real time [20] or to represent a healthcare efficiency transformational initiative [21]. The Emily Couric Clinical Cancer Center in Virginia adopted a RTLS that monitors patients' and providers' transient locations throughout the facility, in an effort to reduce wait times [22]. Enterprise solutions have also been reported and some examples include IBM [23], PINC Solutions [1] or RapidModeling [2].

Proposed RTLS Solution

In the previous section we described several proposals of RTLS implementations that represent a benefit in a hospital environmental and for the health services. In this section, we will describe our solution to track indoor assets also in a hospital environment and the main differences there are with other studies and implementations.

Overview

The main purpose of the system when he was first thought of was to quickly allow a hospital technician to find a given equipment. One of the most relevant scenarios we believe this is truly important to be applied to and can make a difference is when we are talking about equipment that needs to be found within seconds, such as a reanimation machine, and can literally be traduced in life or death situations. Typically, almost all floor of hospitals has nowadays a desktop computer, so doctors and nurses can manage data, so we rely our solution on the existence of that central computer that would allow to quickly:

- Find where a specific equipment is and
- Find the closer equipment of a given type (e.g.: reanima tion machine).

The study we performed went a little further than solely the technological aspects and we made some experiments on how this would work out in a real scenario where there are visitors, walls, curtains, etc. that can block some signals. In the next section we explain the components that our architecture relies on.

Components and Architecture

To achieve our purpose, we first started to decide the technologies to use. As afore mentioned, we rely on the existence of a desktop computer in each floor that has a web page that is provided by a server that receives and handles all data from the location of equipment so searches in real time can be made to locate equipment. Figure 1 shows a possible scenario of the application of our solution and the components involved. Several RPs (figure shows only one for a matter of space) would be applied in each division (how they will be applied will be explained ahead) and they will receive information of the equipment if it is nearby using Bluetooth technology. The RP transmits this information to the central server that handles data and makes it available to whoever is using the desktop computer in each floor.

To set up this scenario, our system is made up of four layers: a data layer, a middleware layer, a server and a visualization layer, as shown in (Figure 2).

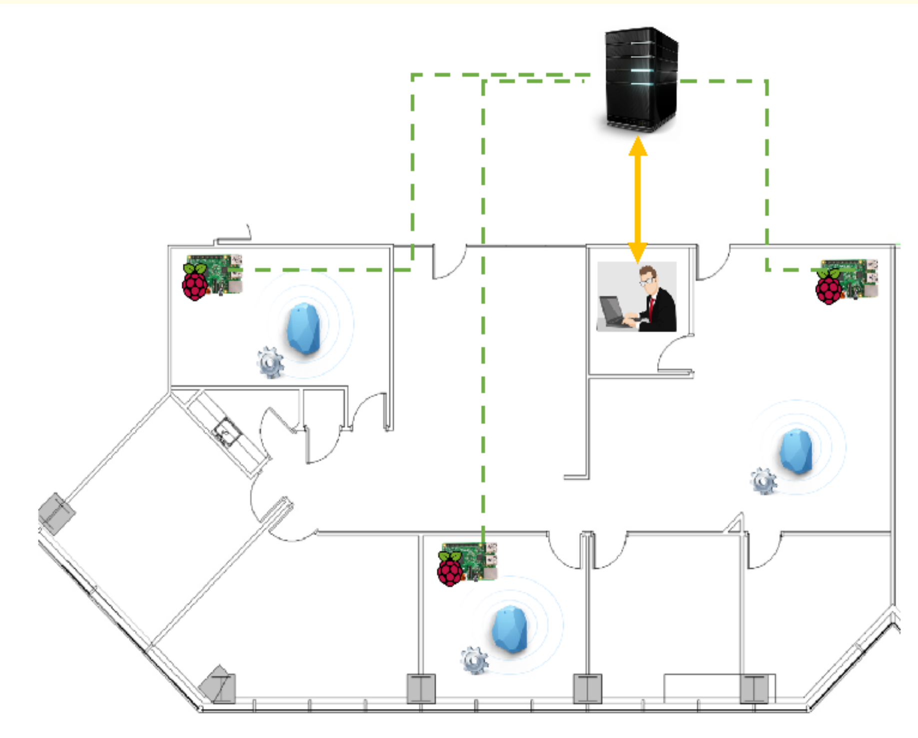

Figure 1: Scenario of the floor and components.

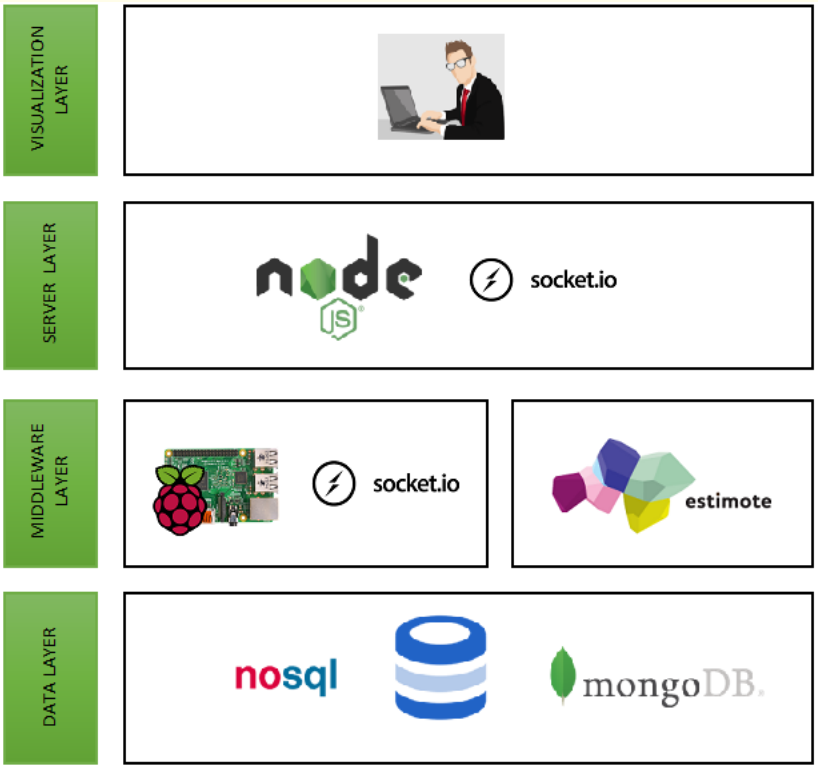

Figure 2: Architectural layers of the system.

The data layer is composed of a NoSQL database, more specifically MongoDB that enables to build application faster, handle highly diverse data types and manage applications more efficiently at scale. The model used is illustrated in figure 3. The middleware layer is responsible for the communication between the beacons and the server which is done using RPs. The Raspberry Pie 3 was the choice as it already includes Wi-Fi and Bluetooth and also because there is an ARM version of Node.JS. To finish the setup of the middleware, it was necessary to configure BlueZ to get the Bluetooth to work in the RP and make Socket.IO to communicate with the server. We also used a Node.JS library (node-eddystone-beacon-scanner by Sandeep Mistry) in order to scan for the eddystone packets. The beacons used were the Estimote Proximity Beacons and the eddystone packets as its telemetry packet that gives us an additional information. The server had to be able to handle web sockets, be lightweight and versatile to be used for more applications. The choice was Node.JS which supports web sockets (with Socket.IO) and has plenty of libraries. Finally, a web application was developed as the visualization layer that allows technicians to perform searches for equipment.

Implementation

In this section we describe details of the design of the solution. Our approach, in order to achieve a better precision in the position of the equipment, was to map the floor of the hospital into coordinates (floors are treated independent from each other). With that mapping made, RPs send captured beacons signals to the central server, where they are processed. This data is then available for personnel to search equipment in a website.

Coordinate map definition

For each floor where we want to track assets, first we need a map of the floor in terms of coordinates. Before being able to track moving equipment, we defined the coordinates of fixed points that are the corners of each room and the position of the receptors (RP). From this point, we can start calculating the position of beacons (moving equipment). This calculation differs depending on the number of receptors that catch the beacon signal. The system supports three situations, of course with different levels of precision: three, two or one receptor catching the beacon signal. This signal,

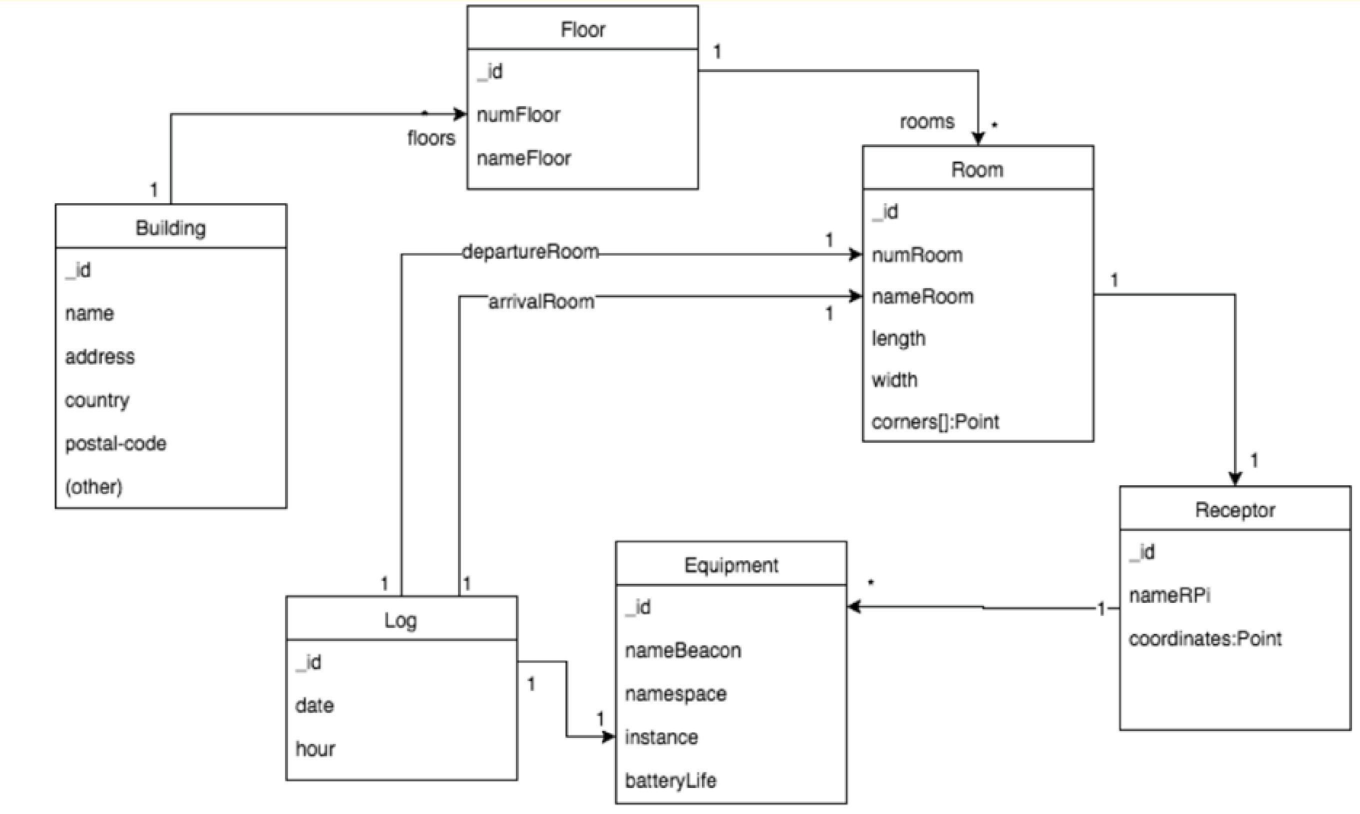

Figure 3: Model of the Mongo DB database.

that is caught by the receptors, is the RSSI which stands for Received Signal Strength Indicator and represents the measurement that indicates how well the beacon is perceived by the receptor. As this value is not the most accurate, we applied the Kalman filter to obtain a more precise value. In the next sections, we explain the application if the Kalman filter, how we calculate distance to the beacon and the three supported situations (three, two or one receptor catching the beacon signal).

Kalman filter

In order to get a smoother evolution of the distance of the beacon to the receptors, we implemented the Kalman filter [24], one of the most widely used methods for tracking and estimation due to its simplicity, optimality, tractability and robustness. This algorithm takes a series of measurement over time containing noises and other inaccuracies and produce a variable that tend to be more accurate than just the raw values. Figure 4 shows values received from beacon signals with and without the Kalman filter, allowing us to conclude we would increase the precision of the system by using it.

Calculate distance

In order to calculate the distance of the beacon to the RP, we use the formula of power regression. The necessary parameters are:

- A0: the txPower of the beacon (which is the physical power of the transmitted signal)
- RSSI: the value obtained from the Kalman filter
- N: the signal propagation, for indoor n = 2
- d: the value we want to obtain

With this information we can apply the RSSI formula given by equation 1

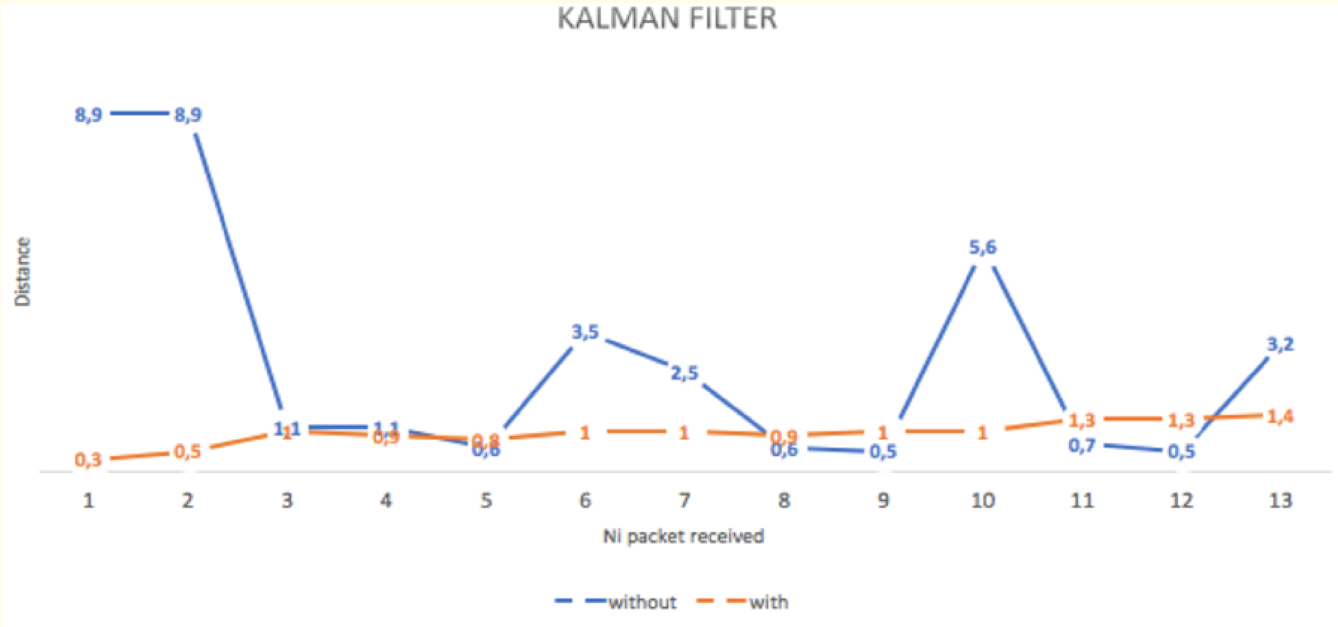

Figure 4: Demonstration of application of Kalman filter to received signals from beacons.

$$A_0 - RSSI = 10 * n * \log(d) \quad \text{(Eq. 1)}$$

If we work the equation we can obtain the one described in equation 2, which provides the value of the distance.

$$d = 10^{\left(\frac{A_0 - RSSI}{10*2}\right)} \quad \text{(Eq. 2)}$$

The distance calculation presented is used to calculate the equipment position within a division.

Coordinates calculation

Figure 5 shows the algorithm used to decide how to calculate coordinates, based on the distance calculation previously presented.

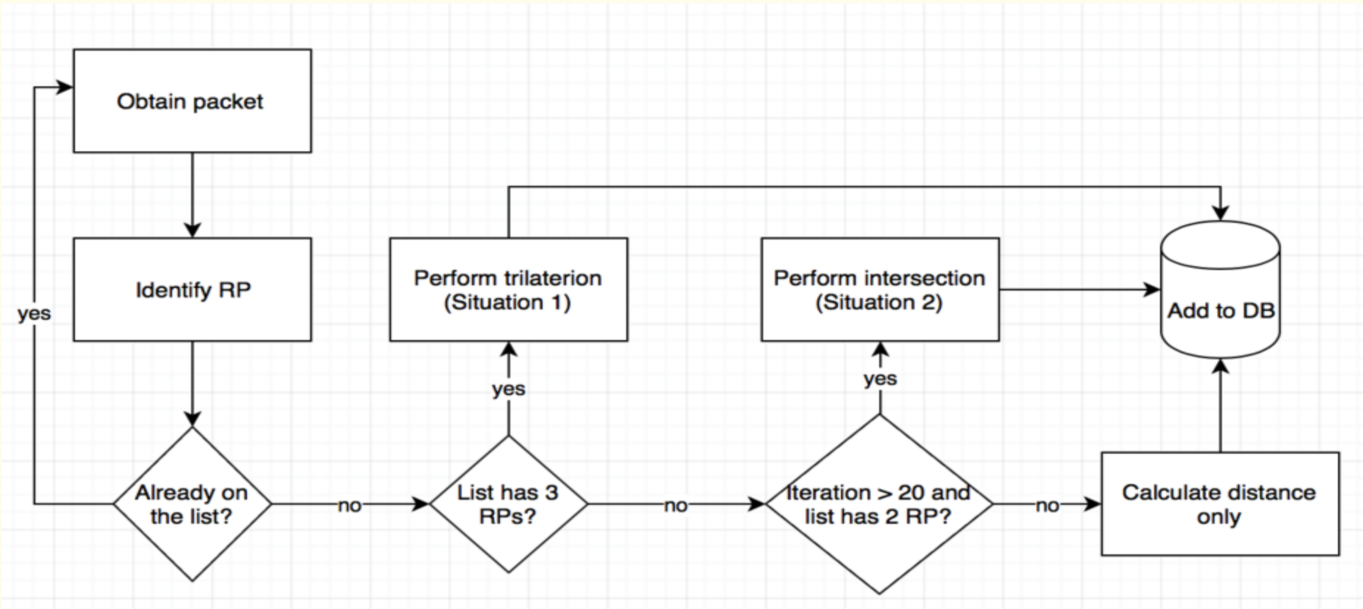

Figure 5: Algorithm to choose best coordinate calculation method.

Whenever a packet is received, the RP is identified and stored in a list, if not previously there. If 3 RPs are in the list, it means that trilateration can be used (Situation 1). If after 20 iterations there are only 2 RPs in the list, then intersection is used (Situation 2). If after those 20 iterations only RP catches a beacon signal, distance is calculated and used as the equipment position directly. In all situations, data is stored in the database for later searches be possible.

Situation 1: Three RP catch beacon signal - Trilateration

This is the most desired situation for the system to calculate the beacon position with more precision as it allows us to use trilateration. The trilateration only uses distances and coordinates to calculate an unknown point in opposite of triangulation that uses angles too. Trilateration uses the geometry of circles, spheres or triangles. Since we have the distance of the beacon from each receptor, we know that it will be in a circle around the receptor at the distance calculated. We also know that, given distances, each circle will intersect at some point and that is what we use. To find the intersection of the three circles, we must formulate the equation for the three circles surfaces and resolve it the two unknowns: x and y. The unknown point is (x, y), the receptors are (x_{ri}, y_{ri}) and we also know each distance r_i.

$$(x - x_{r1})^2 + (y - y_{r1})^2 = r_1^2$$
$$(x - x_{r2})^2 + (y - y_{r2})^2 = r_2^2$$
$$(x - x_{r3})^2 + (y - y_{r3})^2 = r_3^2$$

Expanding each one gives us the following:

$$x^2 - 2x_{r1}x + x_{r1}^2 + y^2 - 2y_{r1}y + y_{r1}^2 = r_1^2$$
$$x^2 - 2x_{r2}x + x_{r2}^2 + y^2 - 2y_{r2}y + y_{r2}^2 = r_2^2$$
$$x^2 - 2x_{r3}x + x_{r3}^2 + y^2 - 2y_{r3}y + y_{r3}^2 = r_3^2$$

If we subtract the first with the second, we get:

$$(-2x_{r1} + 2x_{r2})x + (-2y_{r1} + 2y_{r2})y = r_1^2 - r_2^2 - x_{r1}^2 + x_{r2}^2 - y_{r1}^2 + y_{r2}^2$$

And then subtract the second with the third:

$$(-2x_{r2} + 2x_{r3})x + (-2y_{r3} + 2y_{r3})y = r_2^2 - r_3^2 - x_{r2}^2 + x_{r3}^2 - y_{r2}^2 + y_{r3}^2$$

We now have a system of two equations with two unknown variables:

$Ax + By = C$

$Dx + Ey = F$

After this, we have the position of the beacon, given by x and y. Computationally, all of this is done on the server with algebra.js that allows us to compute equations in JavaScript.

Situation 2: Two RP catch beacon signal - Intersection

In this case, we can make the calculus directly in JavaScript without the use of external libraries. We used a function named inter-

```
function intersection (x0, y0, r0, x1, y1, r1) {
 var a, dx, dy, d, h, rx, ry;
 var x2, y2;
 /* dx and dy are the vertical and horizontal distances between
the circle centers. */
dx = x1 - x0;
 dy = y1 - y0;
 /* Determine the straight-line distance between the centers. */
 d = Math.sqrt((dy*dy) + (dx*dx));
 /* Check for solvability. */
 if (d > (r0 + r1)) {
 /* no solution. circles do not intersect. */
return false;
 }
 if (d < Math.abs(r0 - r1)) {
 /* no solution. one circle is contained in the other */
 return false;
 }
 /* 'point 2' is the point where the line through the circle
 * intersection points crosses the line between the circle
 * centers.
 */
 /* Determine the distance from point 0 to point 2. */
 a = ((r0*r0) - (r1*r1) + (d*d)) / (2.0 * d);
 /* Determine the coordinates of point 2. */
 x2 = x0 + (dx * a/d);
 y2 = y0 + (dy * a/d);
 /* Determine the distance from point 2 to either of the
 * intersection points.
 */
 h = Math.sqrt((r0*r0) - (a*a));
 /* Now determine the offsets of the intersection points from
 * point 2. */
 rx = -dy * (h/d);
 ry = dx * (h/d);
 /* Determine the absolute intersection points. */
 var xi = x2 + rx;
 var xi_prime = x2 - rx;
 var yi = y2 + ry;
 var yi_prime = y2 - ry;
 return [xi, xi_prime, yi, yi_prime];
 }
```

section that takes two receptors coordinates and two distances. We start by calculating the vertical and horizontal distances between the circle centers, then determine the straight-line distance between the centers. From here, what we want to obtain is the point where the line through the circle intersection points crosses the line between the circle centers. Next, we present all the calculations to achieve this point which will be the beacon position, given two receptors catching its signal.

Situation 3: One RP catch beacon signal

This case is rare but still can happen and must be considered. In this case, no coordinates are computed, both are set to -1 and we store in the database only the distance.

Back-end and Front-end

Once the system can recognize the beacons position, which represent moving assets inside a hospital, and they are stored in a database, data needs to be managed and for that a backend and a frontend were developed. The frontend is intended for authorized personnel to search for equipment and quickly find it. The backend functionalities predict the scalability of the system, allowing for new building to be created, floors in it; and rooms in the floors. Figure 6 shows the information necessary to create a building, with its name, address, city and country (Figure 6).

After a building is created, floors should be created with a number and a name, as shown in figure 7.

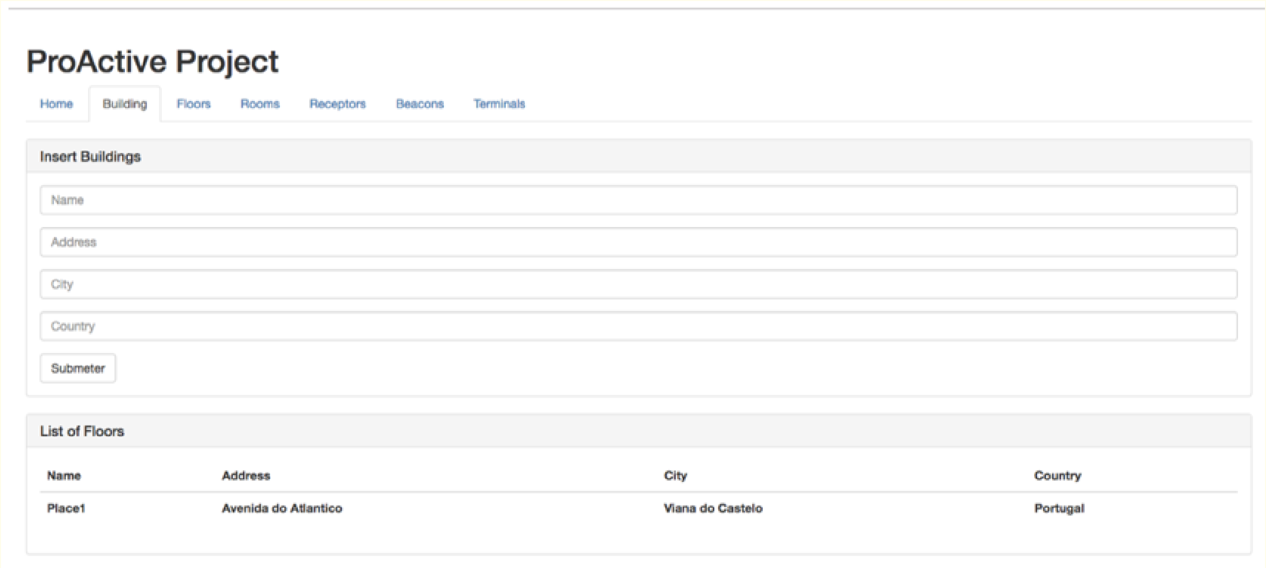

Figure 6: Back-end functionality to add buildings.

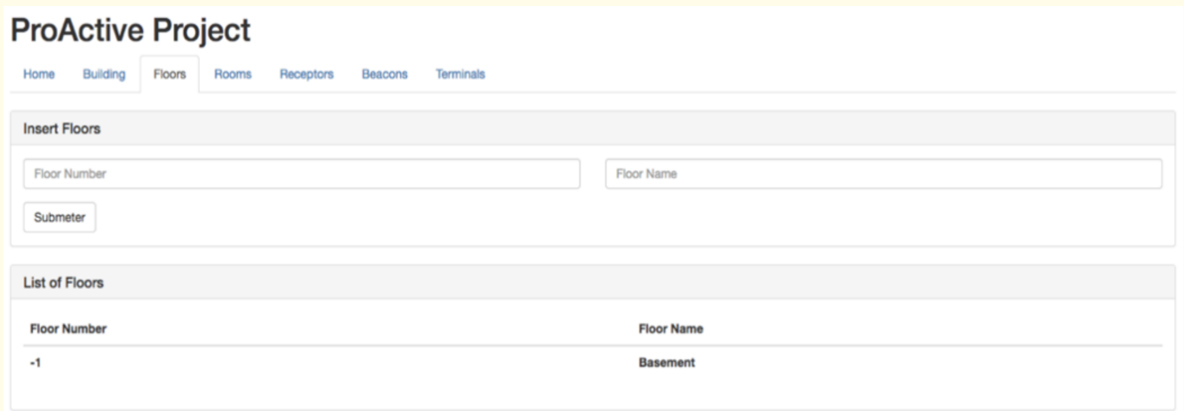

Figure 7: Back-end functionality to add floors to buildings.

When adding rooms, the coordinates have to be defined as shown in figure 8. Each room should have a number, a name, the x coordinate of the bottom left of the room, the y coordinate of the bottom left of the room, the length and width. Some examples of rooms already configured can be seen in figure 8.

Receptors also need to be inserted in the system as shown in figure 9. Each receptor as a room associated to it and also its coordinates, so all algorithms and calculations described above to know the assets position can work.

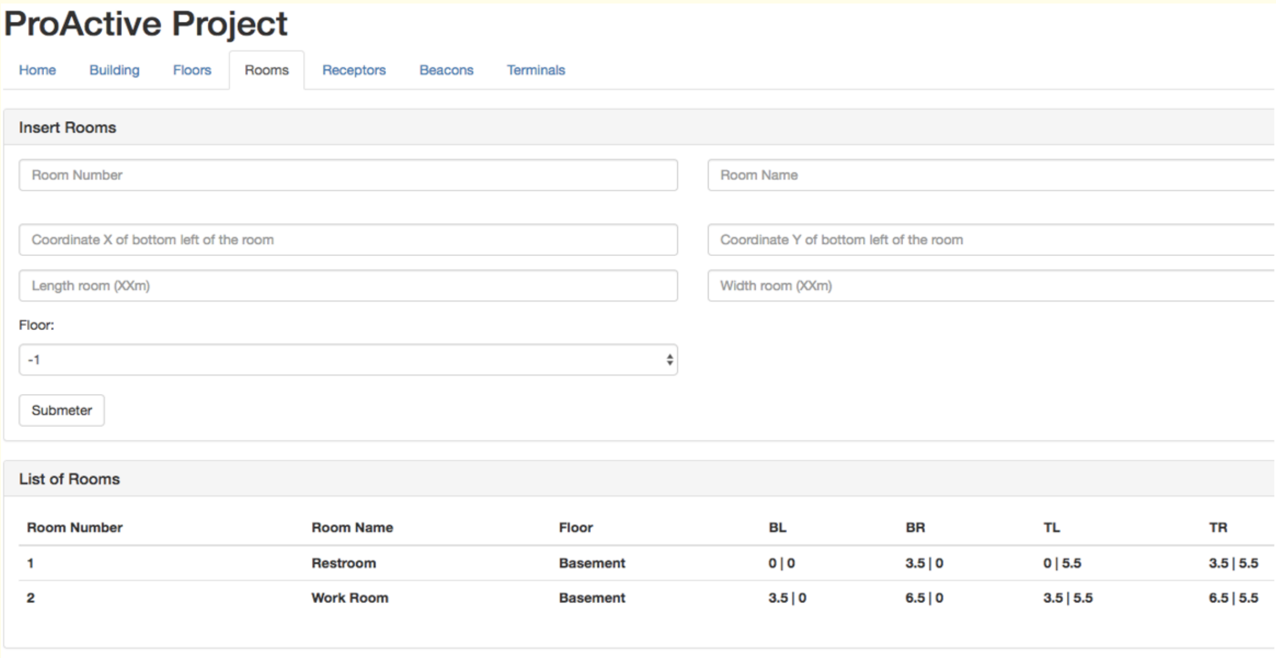

Figure 8: Back-end functionality to add rooms to floors including coordinates definition.

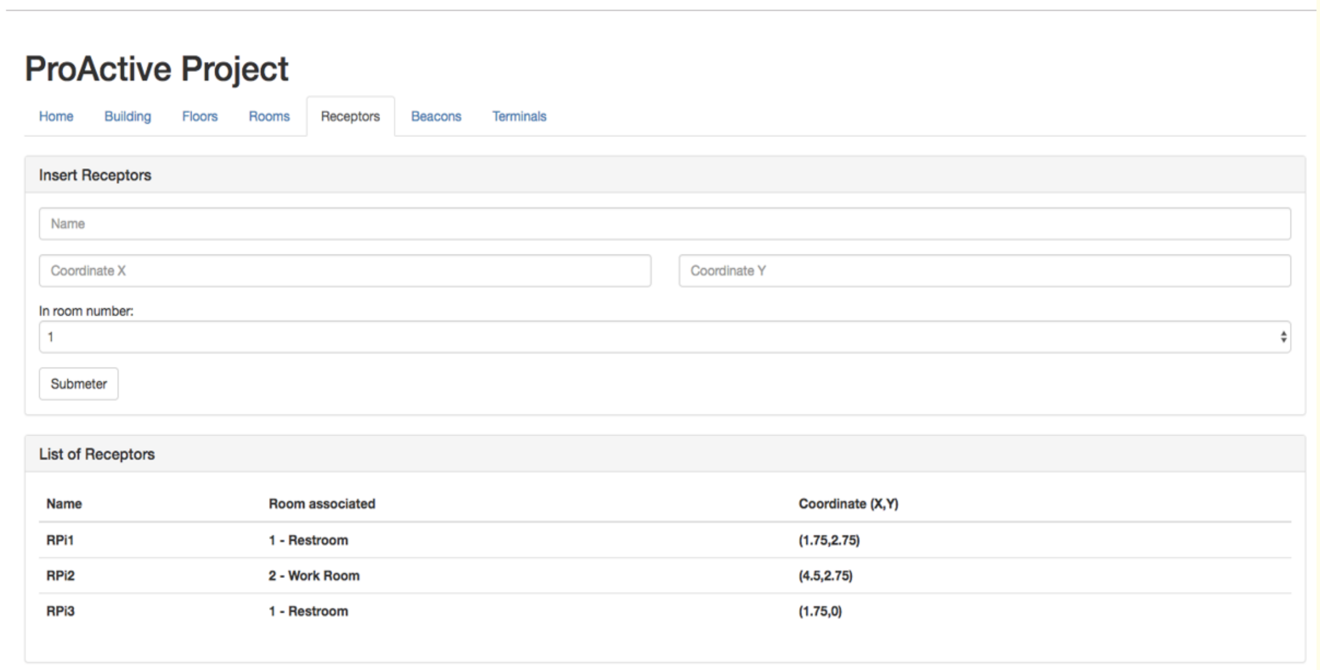

Figure 9: Back-end functionality to add receptors to rooms.

Beacons also need to be added to the system, with the Eddystone namespace and instance, as shown in figure 10. Namespace and instance are configurable in Estimote beacons. Instance is a 12-character unique variable. We configured our beacons so that the first character identifies the floor (1 - First Floor, for example).

When configuring beacons in the Estimote platform, we can configure both namespace and instance, as afore mentioned. Figure 11 has an example of the beacon with the name 'blueberry'. It has an identifier and the Eddystone telemetry was configured so the instance, in this case, starts with a 1, which will automatically allow to know this beacon is associated to a division on the first floor.

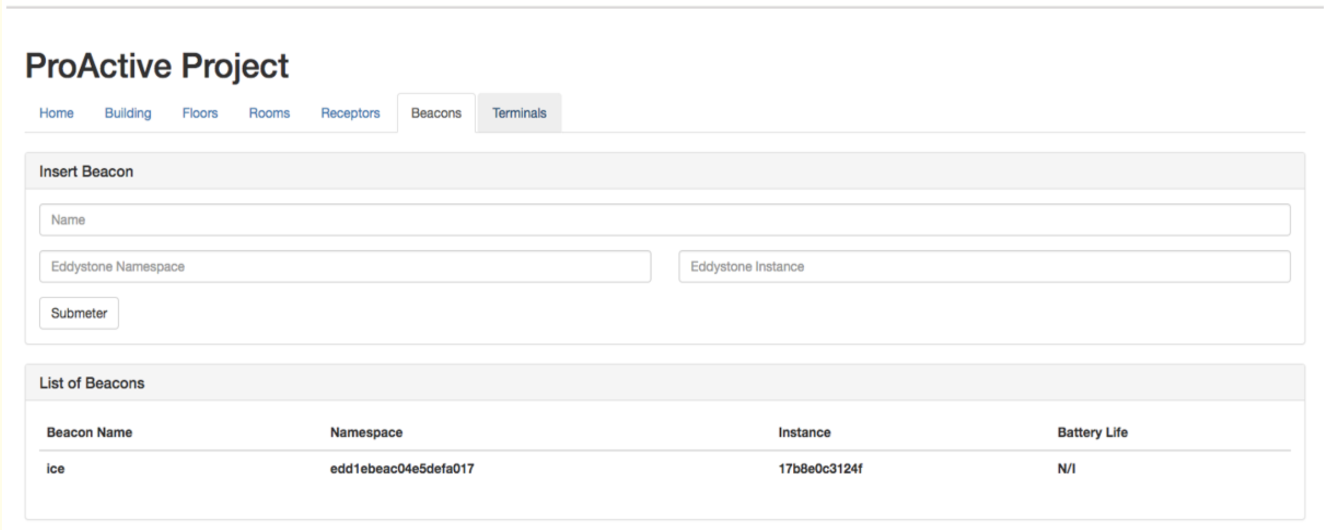

Figure 10: Back-end functionality to add beacons.

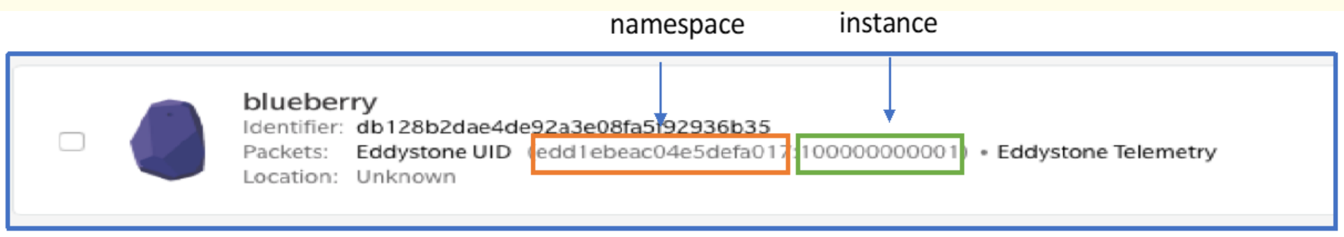

Figure 11: Estimote beacons configuration.

Finally, terminals also need to be added, and they represent desktop computers where searches will be performed by the hospital technicians. As shown in figure 12, terminals have a name, IP address, and coordinates. This information allows searches made in this terminal to return the equipment closer to it.

After the back-end is fully configured, searches can be done by personnel to track and find assets. Figure 13 shows the list of all equipment in floor 1. In this case, there is one equipment named 'ice' (this is in fact the beacon name that would in production receive the name of the equipment) and the correspondent coordinates. The battery life is also presented so it can be replaced when necessary.

Figure 14 shows a specific search for an equipment with a given name. In this case is 'ice' but it could be a reanimation machine or any other suitable name for the equipment. After searching for the device, the closer location is presented which in this case in the restroom of the basement floor.

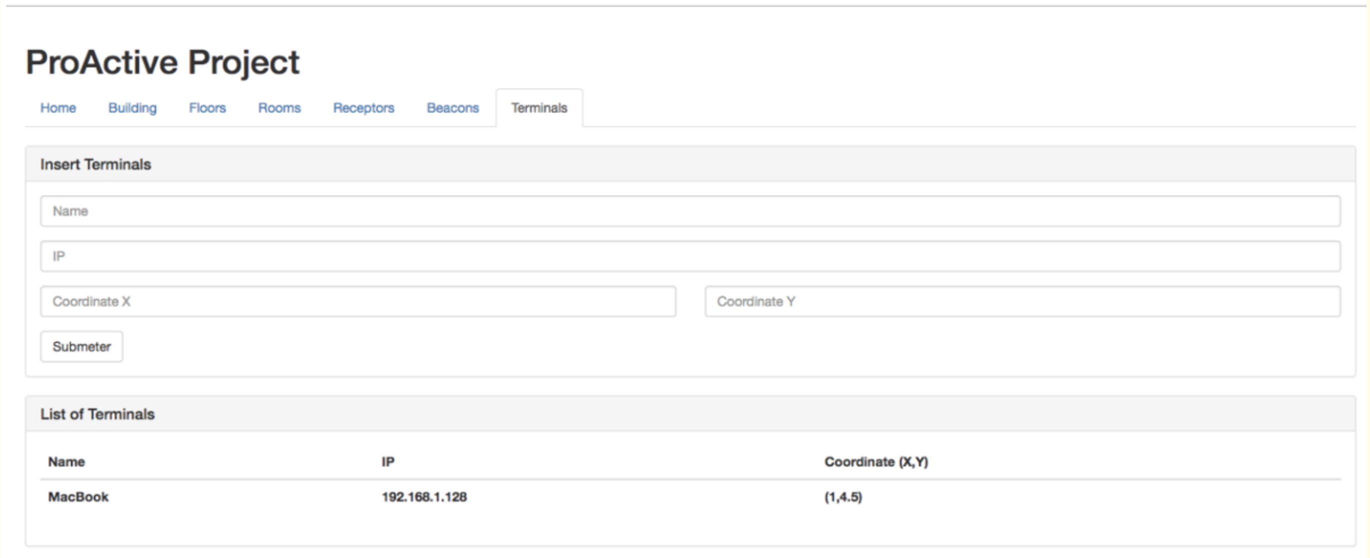

Figure 12: Back-end functionality to add terminals.

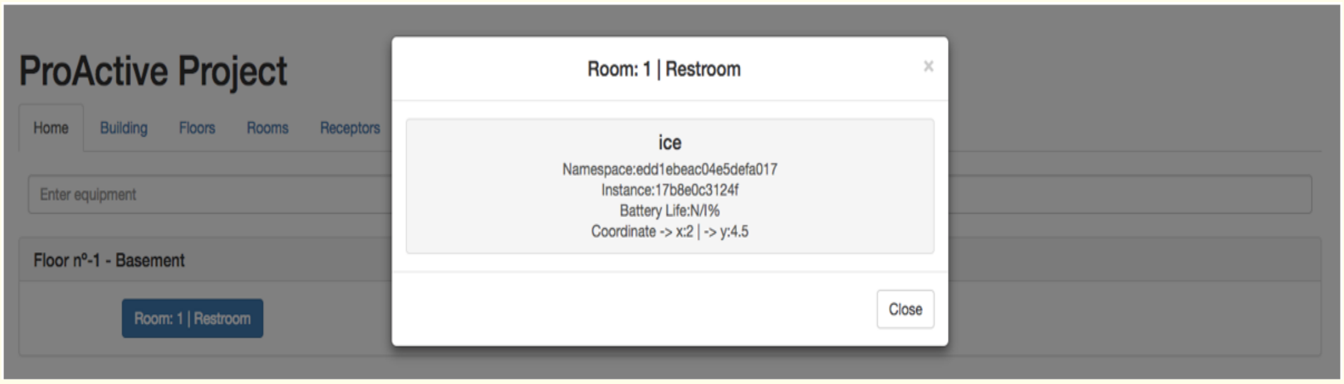

Figure 13: List of all equipment found in floor 1.

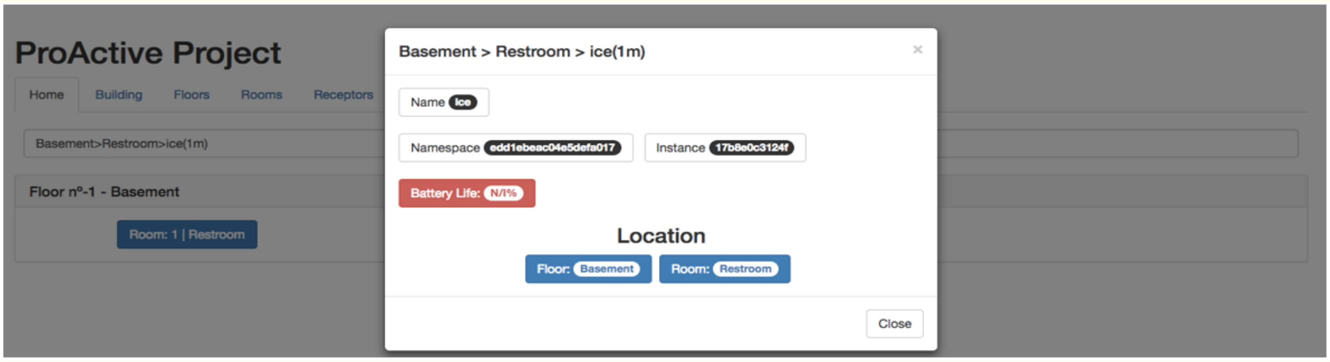

Figure 14: Specific search for an equipment.

Evaluation

The evaluation of this system is fundamental to ensure it has a proper behavior in real scenarios inside a hospital. In concrete, we believe it is fundamental to take into consideration the several materials that buildings are made of and the influence they have on beacons signals, has our system totally rely on the reception of these signals. Beacons, being part of the Radio Frequency family, are sensible to materials just like Wi-Fi is. Some of the situations that are likely to happen in hospitals and that we contemplate in this evaluation are:

Evaluation 1: Given a hospital room, can one bed/machine position be confused with another bed in the floor below (making it a different room?) Certain materials block or help to propagate a signal. In a big building, this can be a problem in a floor level to identify which beacons are in this floor and do not confuse with another floor.

Approach used for evaluation 1: The correct differentiation of beacons in the same floor is handled by the calculation of the coordinates and since the calculations does not involve the z axis, we need some additional information. In our system, each beacon is identified by a namespace and an instance. The namespace is a general tag that could be associated with the family the equipment represents, in our case the hospital. We this in mind, the instance is what identify uniquely a beacon. We need to represent the floor and still uniquely identify the beacon; the instance is represented by a 12-character string long that offers a lot of possibilities to associate identificatory number with. If we take the first character as the representation of the floor, we end-up with 11 characters that still offers plenty of identificatory. If we use the hexadecimal base number to represent the ids, we go from 2.8147498e+14 for a 12-character id to 1.7592186e+13.

Evaluation 2: Given a hospital room, can one bed/machine position be confused with another bed the other side of the wall (making it a different room?). This aspect raises the question of how materials affect beacon signal.

Evaluation 3: Given a hospital room, can curtains or people obstruct the signal and prevent the detection of an equipment? This aspect is also covered by the influence of materials on detecting and catching signals.

Approach used for evaluations 2 and 3: This evaluation has mainly to do with understanding how we can minimize the situations where beacon signal is blocked. There are three situations that we address to evaluate scenarios 2 and 3.

- Placement of receptors
- Interference of materials
- Interference of other signals

Placement of receptors

In order to get the most area covered and to match the characteristics of the RSSI values and coordinate system, the placement of the receptors have to be in a high place. Covering them in a surface where people can have access too isn't a good idea. The best solution is to place them on the ceiling, in the center of the room.

Interference of materials

Another aspect very important for these two evaluations is to study typical materials that are part of buildings and understand how beacon signals can be affected by them. A list of materials and their level of interference is shown in table 1.

Interference potential	Material types
Low	Wood, synthetic materials and glass
Medium	Bricks and marble
High	Plaster, concrete and bulletproof glass
Very high	Metal, water

Table 1: Interference potential of several material types.

Note that the water type is equivalent to the human body due to his composition of 70%. To test the interference of materials on our solutions and understand the adjustments we would need to do, we used several materials at a 2 meters distance between the receptor and the beacon. For the tests, the following materials were used: wood, brick, concrete low thickness (< 5 cm) and concrete high thickness (> 30 cm), metal low thickness (< 5 cm) and metal high thickness (> 30 cm), crowd (water). The concrete and metal scenario had to be split in two categories to represent better the impact that they have, since their potential in interfering with the signal is high.

The first test results are shown in figure 15 and show that the lowest values of RSSI are obtained with people around the beacon (water) and concrete/metal high thickness.

Another test was made regarding the distance signals received with the interference of the materials. Results are shown in figure 16 and, once again, water (people) represent the highest interference, resulting in a lower number of packets received.

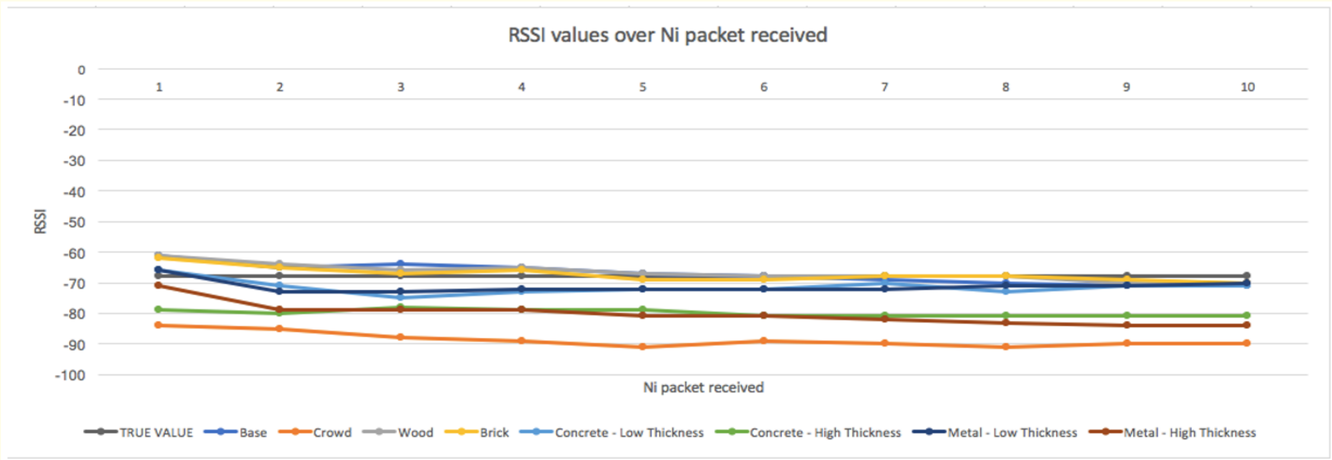

Figure 15: RSSI values over time for each material.

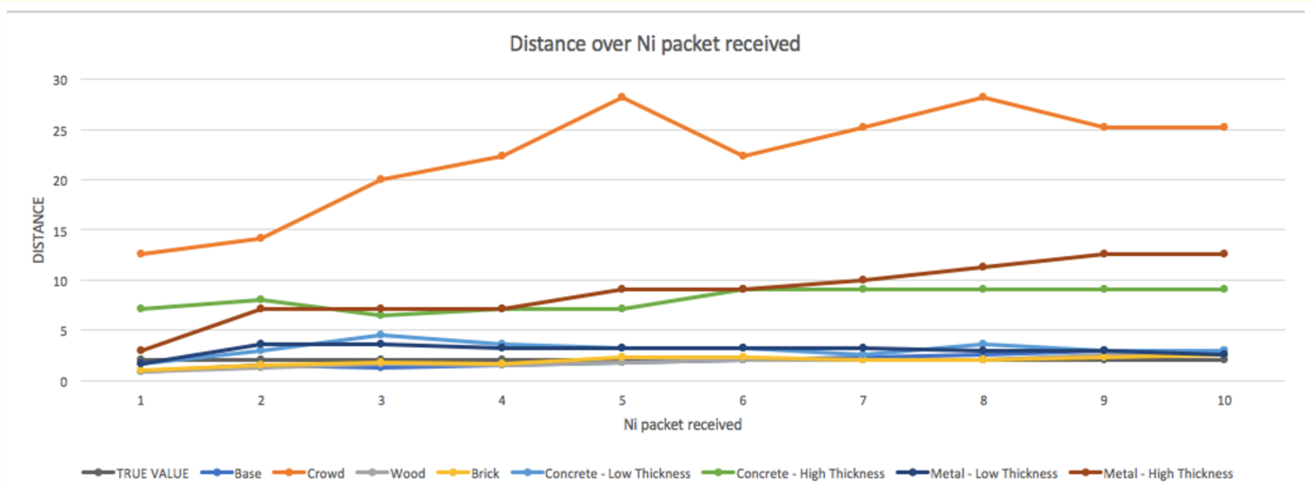

Figure 16: Distance over time for each material.

Interference of other signals

Bluetooth belongs to the 2.4G Hz bandwidth, making it another equipment using it. The most common signal that we can find in every corner and can interfere with the beacons that belongs to the same bandwidth is the Wi-Fi signal. Correctly used, there is not any problem with the co-existence of both signals. The best practice for Wi-Fi configuration is enabling Wi-Fi on one of the following channels: 1, 6, 7, 8, 9, 10, 11, 12. Other channels (2, 3, 4, 13, 14) might cause interference with Bluetooth signal and it's best to avoid them.

Discussion

As we demonstrated at the beginning of this paper, there are several reported studies of RTLS adoption in hospital settings. The objectives underlying this use may be of a diverse nature such as ensuring patient quality and safety parameters; identifying, locating, monitoring patients, visitors, physicians, auxiliaries, equipment and objects; combat the effects of overcrowding; improve the efficiency of hospital processes. Technologies, as we´ve also discussed previously, are continuing to emerge and new ones arise every day that can have better efficiency and precision.

We introduced and detailed demonstrated an architecture that can be implemented in a hospital with the main purpose to allow personnel to quickly find urgent medical equipment. Beside presenting the technology behind it, we also made some experiments regarding this adoption and we showed them in the previous section. They allowed us to conclude that the proposed system could have a normal behavior in non-visit moments as medical staff and patients are the only ones present in rooms. This scenario assures beacon signals are not obstructed and, therefore, are caught by receivers and allow the system to fully function. In visit-moments, and because people represent mostly water, there might be indeed some problems. To avoid and overcome then, we recommend the placement of several receptors in rooms that are larger, so a better reception of signal from the beacons is possible. Regarding concrete, another material that did not obtain good results in the tests, it can also be a problem in buildings that have these materials between rooms.

Although we are aware of the limitations of wireless technologies and signals interference, we presented an architecture to locate equipment inside a hospital that can have a good performance in a not-crowded environment inside a hospital, considering the recommendations regarding the placement of receptors are followed.

Conclusion

Real Time Location Systems are being used for many purposes and plenty of studies are reported of their adoption in hospital environments. We started this paper by presenting with some detail technologies associated to Real Time Location Systems and also provided several examples of how they are being used in hospital such as for ensuring patient safety, identifying, locating and monitoring people and equipment, fighting effects of overcrowding or improving the efficiency of hospital processes.

After, we presented our own proposal of a server-based positioning system using Bluetooth low energy technology (beacons) for tracking assets in hospitals. The major purpose behind our proposal was the response to the need to find certain equipment, such as a reanimation machine, that has to be found within seconds, and that can represent saving a life.

Our solutions use beacons that communicate with Raspberry Pie's which sends data to a server, so gathered data can be searched by technicians to find equipment. The main purpose is for personnel, using a desktop computer that we assume to exist in each floor, to quickly find an equipment. The solution requires each building, floor, room, equipment, receptor and terminal to be configured through a backend, so coordinates of a given equipment can be calculated.

We presented in detail the algorithms for calculating the distance between Raspberry Pie and beacon and also the beacon final coordinates. For this, we separated three possible situations: beacon signal is caught by 3 receptors and trilateration method is used; beacon signal is caught by 2 receptors and intersection is used; beacon signal is caught by 1 receptor and direct distance is used.

We also presented the results of tests made regarding the three major scenarios we identified has a potential problem: clear distinction between floors, clear distinction between adjacent rooms and effect of other material (people, curtains). The interference of materials represents the major issue and we have reached the conclusion that water (people) and concrete high thickness are the worst scenarios for the system we designed. Not all building is made of concrete high thickness so in this cases confusion between adjacent rooms would not be a problem. People are in fact the biggest problem, as they are mostly water, but we believe this will only represent a problem in visit moments and if the equipment is blocked by all of them. Even so, we suggest having more than one receptor in bigger rooms so RSSI signals can be caught with better quality and contribute to a better behavior of the global system, with higher precision in the calculated coordinates.

Bibliography

1. PINC. (n.d.). "Mobile Asset Tracking with Real-Time Location Systems (RTLS): The Real-Time Visibility Enabler for a Global Supply Chain".
2. NE Lee. "RTLS and the Built Environment RTLS and the Built Environment" (2010).
3. D Brito., *et al*. "Server-based Positioning System using Bluetooth Low Energy Technology for Tracking Assets in Hospitals". *International Journal of Engineering and Technology (IJET)* (2018): 780-785.
4. B Wang., *et al*. "Evaluation of RFID and Wi-Fi technologies for RTLS applications in healthcare centers". 2013 Proceedings of PICMET '13: Technology Management in the IT-Driven Services (PICMET) (2013): 2690-2703.
5. Malik A. "RTLS For Dummies". *Indianapolis Indiana Wiley Publishing* (2009).
6. S Nibbelink. "A primer on RFID and RTLS technologies for healthcare facilities" (2012).
7. Yazici HJ. "An exploratory analysis of hospital perspectives on real time information requirements and perceived benefits of RFID technology for future adoption". *International Journal of Information Management* 34.5(2014): 603–621.
8. RM Jochem. "Accepting and engaging with a real-time location system in a hospital context". Eindhoven University of Technology (2017).
9. Ohashi K., *et al*. "Smart medical environment at the point of care: Auto-tracking clinical interventions at the bed side using RFID technology". *Computers in Biology and Medicine* 40.6 (2010): 545–554.
10. Vilamovska AM., *et al*. "Study on the requirements and options for RFID application in healthcare". (2009).
11. Potisek NM., *et al*. "Use of patient flow analysis to improve patient visit efficiency by decreasing wait time in a primary care-based disease management programs for anticoagulation and chronic pain: a quality improvement study". *BMC Health Services Research* 7.1 (2007).
12. Fisher JA and Monahan T. "Evaluation of real-time location systems in their hospital contexts". *International Journal of Medical Informatics* 81.10 (2012): 705-712.
13. Janz BD., *et al*. "Information systems and health care-II: Back to the future with RFID: Lessons learned-some old, some new". *Communications of the Association for Information Systems* 15.1 (2005).
14. Wang SW., *et al*. "RFID application in hospitals: a case study on a demonstration RFID project in a Taiwan hospital". In System Sciences 2006 HICSS'06. Proceedings of the 39th Annual Hawaii International Conference on 8 (2006).
15. I D' Souza., *et al*. "Real-Time Location Systems for Hospital Emergency Response". In IT Professional 13.2 (2011): 37-43.
16. AAN Shirehjini., *et al*. "Equipment Location in Hospitals Using RFID-Based Positioning System". In IEEE Transactions on Information Technology in Biomedicine 16.6 (2012): 1058-1069.
17. R Miclo., *et al*. "RTLS-based Process Mining: Towards an automatic process diagnosis in healthcare". 2015 IEEE International Conference on Automation Science and Engineering (CASE) (2015): 1397-1402.
18. G Han., *et al*. "Testing a proximity-based location tracking system with Bluetooth Low Energy tags for future use in the OR". 2015 17th International Conference on E-health Networking, Application and Services (HealthCom) (2015): 17-21.
19. A Simmons. "Improved OR Patient Flow Through RTLS-Based Visual Analytics". In Healthcare Information and Management Systems Society (HIMSS) (2016).
20. N Siva and A Rajesh. "RFID-Based Hospital Real Time Patient Management System". *International Journal Computing Trends in Technology* 3.3 (2012): 509-517.
21. Z Smith. "VA Real Time Location System (RTLS) Overview". *NESCE Healthcare Symposium* (2014).
22. A Ewing., *et al*. "A systems approach to improving patient flow at UVA Cancer Center using Real-Time Locating System". 2017 Systems and Information Engineering Design Symposium (SIEDS) (2017): 259-264.
23. G Buchan. "Real Time Location Services and Asset Management". (2009).
24. SJ Julier and JK Uhlmann. "A New Extension of the Kalman Filter to Nonlinear Systems". Proceedings of the Signal Processing, Sensor Fusion, and Target Recognition 3068 (1997): 182–193.

Volume 2 Issue 7 October 2018