BLE supported indoor location

Subtitle

Ricardo Pacheco Pais Martins

Thesis to obtain the Master of Science Degree in

Elecrical and Computer Engineering

Supervisor(s): Prof./Dr. Lorem Ipsum

Examinatiom Committee

Chairperson: Prof. Lorem
Supervisor: Prof. Lorem Ipsum
Co-Supervisor: Prof. Lorem Ipsum
Members of the Committe: Dr. Lorem Ipsum
Prof. Lorem Ipsum

March 2017

Anyone who has never made a mistake has never tried anything new.

Albert Einstein

Acknowledgments

I would like to thank the Academy,laura, jnos, pais, pais da laura, leal , almeida etc... bla bla bla..

Abstract

The Objective of this Work ... (English)

Keywords

Keywords (English)

Resumo

O objectivo deste trabalho ... (Português)

Palavras Chave

Palavras-Chave (Português)

Contents

List of Figures

List of Tables

Abbreviations

GPS Gloobal Positioning System

LAN Local Area Network

BLE Bluetooth Low Energy

LE Low Energy

RSSI Received Signal Strength Indicator

IoT Internet of Things

SMP Security Manager Protocol

PHY Physical

QoS Quality of Service

L2CAP Logical Link Control and Adaptation Protocol

HCI Host Controller Interface

P2P Peer-to-Peer

ATT Attribute Protocol

GATT Generic Attribute

GAP Generic Access Profile

FDMA Frequency Division Multiple Access

TDMA Time Division Multiple Access

RF Radio Frequency

US Ultrasound

RFID Radio Frequency Identification

WLAN Wireless Local Area Network

CSI Channel State Information

LOS Line-of-Sight

IR Infrared

UWB Ultra-Wideband

ToA Time of Arrival

TDoA Time Difference of Arrival

RToF Roundtrip Time of Flight

AoA Angle of Arrival

FM Frequency Modulation

CoO Cell of Origin

DR Dead Reckoning

List of Symbols

1

Introduction

Contents

The development of navigation systems began in the 1930's with the second world war and opened the door for a continuous research for better and more precise systems capable of providing real-time locations under any circumstances. The most widely known positioning system is the Gloobal Positioning System (GPS), a system whose development begun in the 70's with a military purpose in mind, and is nowadays available and used by everyone with a capable device, be it a smartphone, a portable GPS-device or even a car with incorpareted GPS system. This passage occored over the last few years with the advancement of technology and allowed it to become more and more something readily available to anyone, which then allowed for outdoor location to become something of our everyday life in the form of navigation systems, with its most widely used application being google maps.

With the GPS taking the crown in the outdoor location system due to its incomparable success, the research target changed to indoor location but since it's an outdoor position systems based on a network of satelite, when the required scenario for position tracking is the inside a building, new constraints are presented onto the process such as the attenuation and reflection of eletromagnetic waves upon collision with building walls and obstacles [1]. As such there was a need to find reliable indoor systems that by nature would already be able to heavily reduce the impact of some of the mentioned constraints.

In order to understand indoor position there is a need to understand the full scope of variables that come to surface when moving from outdoor to indoor. When developing an indoor system there is a need to make sure that it can tackle chalenges such as: small space dimension, which reforces the need for higher precision; a higher probability of non existent line of sight; influence of obstacles such as walls, furniture and moveable objects such as doors and human beings [2]. All of the previously mentioned affect the way electromagnetic waves propagate in an indoor environment leading to problems related to severe multipath and reflection on existent surfaces [3]. Besides propagation challenges, there are energy consumption, accuracy and deployment costs that play a critical role in deciding the viability of a proposed indoor location technique.

Indoor positioning systems research has been capable of introducing new technologies other than satellites, whose most relevant characteristic is that they are deplayed site-wise and as such have a much smaller range and are capable of at least providing a much clearer line of sight between deplyed device and target, which was the hardest obstacle to GPS due to the fact that it's a satellite-based system. These smaller scale technologies are ment to be deplayed inside building and in much greater number due to their reduced cost. Over the course of the last ten years, the technologies that were indicated as the ones capable of providing a better indoor location system have been everchanging as with time the technologies themselves have evolved aswell. One of the biggest factors for it has been the evolution of mobile devices which have greatly evolved and have now available a far superior range of different sensors, higher processing capacity and different technologies such as Bluetooth Low Energy (BLE), Wi-FI or Radio Frequency Identification (RFID). As such smartphones have made introduced new possibilities to the world of indoor location such as GPS-based technologies, using high sensitivity antenas to overcome GPS's indoor issues, RFID , Wireless Local Area Network (LAN)

and Bluetooth among others, allowing even for hibrid systems which make use of more than one of the technologies mentioned above. [1, 3, 4].

This chapter provides an overview of the Thesis. Section 1.1 lays out the motivation and the context of the problem being analyzed and section **??** presents the current state of indoor location systems. The contributions of this work are presented on section 1.3 and 1.4 outlines the rest of the work.

1.1 Motivation

The success of GPS as an outdoor location system and its difficulties to have the same success in the indoor location system's environment sparkled the research for different technologies capable of fillinf the hole. As such in the last fifteen years many indoor system's have been created which attempted to solve the problem using one or more technologies, each with their strengths and weaknesses.

With the advencement of smartphones they are now capable of providing many more tools that can be useful for indoor location such as GPS, Wi-Fi, GSM, camera, FM radio, Bluetooth and microphone. Beside these tools, nowadays they even have inertial sensors such as accelerometers, gyroscopes or digital compasses which ,together with ones that were previously mentioned, provide a wide variaty of possibilities. Since this field is still in development and there is a big amount of different scenarios in which it has to be applied that consequently brings onto the table different objectives and requirements, every existant solution can be useful for a certain amount of cases due to the nature of each of them. As such there is a huge quantity of existant solutions that have been researched for each technology which then can even branch out according to all the possible optimizations that have to be applied in order to achieved the project's requirements.

This occurence has led to a need to registrate the state of the indoor location which has been fulfilled by all the existing surveys on the existant technologies [4**?**], which gather up all the existant technologies in the field and analyze them according to their cost, precision, energy efficiency, scalability, privacy, among others criteria. Other surveys analyze technologies on a more specific level by foculizing on existant projects to compare their performances [3]. Another relevant aspect that has been surveid is the existant techniques utilized [1, 2] by analyzing the different metrics utilized to calculate a user's position and comparing their strengths and weaknesses according to coverage, line-of-sight and multipath problems and cost.

This work saw in this situation an opportunity to create a generic architecture that would be capable of deploying any of the existant systems. With all the existant work related to improving a certain technology's performance there was an higher interest in on the possibility of integrating multiple existant works than further improving a single case.

In order to implement the created architecture I used bluetooth low energy since it's a recent technology that is trying to improve its core in order to be usable on Internet of Things (IoT) and it was capable of providing room-based accuracy without much effort on the algorithm department. The

final implemented solution can be visualised on figure 1.1, which has the BLE tags, the smartphone application, the python location server and utlizes the google maps as map provider.
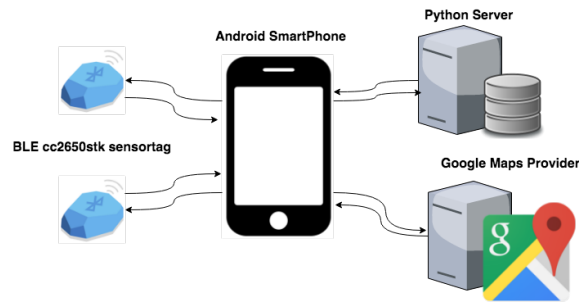
Figure 1.1: Implemented system

1.2 State of The Art

State of The Art Section.

1.2.1 Dummy Subsection A

State of Art Subsection A

1.2.2 Dummy Subsection B

State of Art Subsection B

1.3 Original Contributions

Contributions Section.

1.4 Thesis Outline

Chapter 2 of this thesis analyzes the technology that's utilized in the implemented solution,bluetooth low energy's architecture and functionality. The different manners of obtain the metrics utilized to obtain an object's position as well as some location algorithms are also reviewed in this chapter, which is finalized by overview existant related work, from the older ones that functioned as reference in the field to more recent work using BLE. Chapter 3 presents the architecture of the projected generic indoor system by analyzing each component according to its responsabilities while chapter 4 demonstrates the implemented BLE solution based on the previously presented generic architecture.

2

Indoor positioning

Contents

This chapter gives an overview of the state of the art of Indoor positining solutions. The Bluetooth Low Energy (BLE)'s architecture and functionality is analyzed in section 2.1, while section 2.2 overviews the other existing technologies. The most common techniques utilized for position computation along side examples which make use of them are explained in section 2.3. Finnally on section 2.4 analyzes the most projects that had the most relevance in the field and the existing work related to BLE.

2.1 Bluetooth Low Energy

Bluetooth is a wireless technology that was created in 1994 with the objective of replacing cables connecting fixed or portable devices. At this point in time Bluetooth Special Interest Group is in charge of developing and managing this technology characterized by its robustness, low energy consuption and low cost.

The BLE protocol was introduced with the Bluetooth Core Specification version 4 (also called Bluetooth Smart) circa 2010 alongside two other protocols. Out of the three, BLE standed out for its lower power consumption, lower complexity and lower cost, while allowing for device discovery, connection establishment and connection mechanisms. Due to its characteristics, the BLE protocol was utilized in various IoT applications.

2.1.1 BLE's Architecture

Bluetooth's Architecture is everchanging and can become very complex rather quickly with the introduction of different types of protocols. When working with BLE it's important to understand the key components of its architecture because by doing it's possible to better analyze the role of each component and how they operate and depend on each other. There are two main groups of core blocks, the Low Energy (LE) Controller and the LE Host, in 2.1.1.A and 2.1.1.B respectively, and most the most relevant of these components will now be looked at.
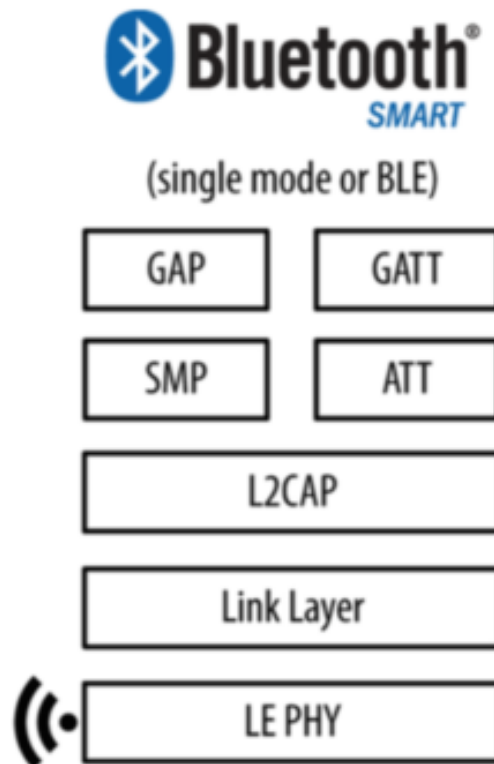
Figure 2.1: BLE architecture

2.1.1.A   LE Controller Group

Physical (PHY) Layer - Architectural block responsible for all Bluetooths' communication channels on the 2,4GHz radio. Receiving and transmitting packets and supplying information crucial for controlling its timing and frequency through the baseband block.

Link Layer - Architectural block responsible for managing logical links between BLE devices. It can create and release connections, update connection parameters related to PHY links. It's responsible for the discovery and consequently connection procedure and also sending and receiving data.

Device Manager - Architectural block responsible for controlling the general behaviour of the Bluetooth device. This block is responsible for all operations that aren't directly related to data transportation. Some of its operations are: inquiring for the presence of nearby BLE devices; connecting to a BLE device; setting whether or not its local device is discoverable and/or connectable by the others; controlling device behaviour such as managing own's local name or stored keys.

Baseband Resource Manager - Architectural block responsible for all acess to the radio medium, this means acess to the PHY channels. It has two porpuses, first to negotiate contracts with the entities that wish to use the medium and second to act as a scheduler on the same radio medium, granting the entities with said contracts, a time window in which they can utilize the medium. A contract is basically a commitment to deliver a certain Quality of Service (QoS) on the user application.

Link Controller - Architectural block responsible for the encoding and decoding of Bluetooth packets from the data payload and parameters related to the physical channel, logical transport and logical link. It also carries out the Link Layer protocol in conjunction with Baseband manager's scheduling

function to communicate flow control and acknowledgement and retransmission request signals.

2.1.1.B   LE Host Group

Logical Link Control and Adaptation Protocol (L2CAP) - Architectural block responsible of transmits packets to the Host Controller Interface (HCI) or directly to the Link Layer in hostless systems. It allows for higher-level protocol multiplexing, packet segmentation and reassembly, and the conveying of QoS information to higher layers.

Channel Manager - Architectural block responsible for creating, managing and closing L2CAP channels used in transport of service protocols and application data streams. The local Channel Manager makes use of the L2CAP protocol to communicate with a peer's Channel Manager and together create L2CAP channels and connect their endpoints to the appropriate entities.

Security Manager Protocol (SMP) - Architectural block responsible for implementing the Peer-to-Peer (P2P) protocol that operates over its own dedicated L2CAP channel and generates encryption keys and identity keys. This block is also in charge of storing those same keys and making them available to the controller. These keys are later used in the encryption or pairing procedures.

Generic Access Profile (GAP) - Architectural block responsible for working in conjunction with Generic Attribute (GATT) to define the base funcionality of BLE devices. The available services in this profile are: BLE device discovery, connection modes, security, authentication, association models and service discovery. GAP defines four different roles to describe a device, allowing for the controllers to be optimized in funtion of the device's desired roles. **Broadcaster:** This role is optimized for transmitter-only applications. In a scenario in which a device supports this role it will make use of advertising in order to broadcast its data. The broadcaster role doesn't support for connections.

Observer: This role is optimized for receiver-only applications and it's complementary to the broadcaster role. It only receives broadcast data included in advertising packets and much like its counterpart, it doesn't support connections.

Peripheral: This role is optimized for devices that only want to suppot a single connection, allowing for a much less complex controller due to the fact that it only needs to support the slave role and not the master one.

Central: This role supports multiple connections and funtions as the initiator for all of them. These connection are all made with Peripheral devices and its controller must support the master role in a connection and allow for more complex funtions, in comparison to the remaining roles.

Attribute Protocol (ATT) Protocol - Architectural block responsible for implementing the P2P protocol between an attribute server and client. This client/server communication happens in a dedicated fixed L2CAP channel. A server can send through this channel responses, notifications and indications, while the client can send requests, commands and confirmations. This block allows the clients to read and write values of attributes on a peer device acting as a ATT server.

GATT Profile - Architectural block responsible for creating a framework for the ATT, in which it is represented the funcionalities of an ATT server. This profile describes the hierarchy of services, characteristics and attributes existent in the server and provides an interface for discovering, reading,

writing and indicating service characteristics and profiles. A more thorough description of profiles can be found in 2.1.2. GATT also defines two possible roles, which aren't directly tied to the GAP roles previously presented but can be specified by higher layer profiles. **Server:** A GATT server is responsible for storing data transported over the ATT and accepts ATT requests, commands and confirmations from a GATT client. It also sends responses to requests and, if implemented, send indication and notification asynchronously to a GATT client when specified events occur on the GATT server.

Client: A GATT client has all the functionalities presented in the GATT server description.

2.1.2 BLE Profiles

Bluetooth profiles defines the required functionalities of each layer, from the PHY to the L2CAP layer, aswell as the the vertical interactions between layers and P2P interactions between device and a specific layer. Since a profile also defines application behaviour and data formats, we can say that when two devices comply with all the requirements of a Bluetooth profile, application interoperability is achieved. Each Bluetooth profiles describes its requirements necessary for devices to create a connection, to find available services and connection information required for making application level connections.

The base profile that any Bluetooth system needs to include is the GAP, already presented in 2.1.1.B. From this point, any additional profile implemented will be a superset of GAP, where GATT is included. Among all that was already introduced about GATT in 2.1.1.B, it also specifies the profile hierarchy, or the structure in which profile data is exchanged. 2.2 shows the hierarchy in a Gatt-based profile, with the profile being the top level and services and characteristics below. The last two will now be presented individualy:

Service: A profile is composed by one or more services. CITAÇÂO CORE PAGE 256 A service is a collection of data and associated behaviors to accomplish a particular function or feature of a device or portions of a device. It can be either primary, which provides primary funcionalities of a device, or secundary, providing auxiliary functionalities of a device and is referenced from at least one primary service. A service is composed of characteristics and/or references to other services.

Characteristic: A Characteristic is a value that is used in a service that has properties and configuration information that descrive how the value should be accessed as well as information on how to display the value. A characteristic is defined by its declaration, its properties, its value and may also be defined by its descriptor, which describes the value or permit configuration of the server relative to the value.
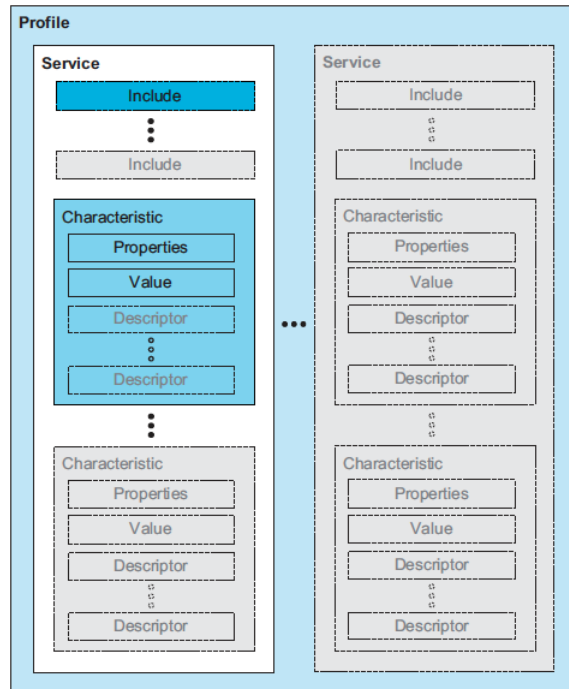
Figure 2.2: Gatt-based profile hierarchy

2.1.3 Communication Topology and Operation

The LE radio operates at the 2.4GHz band and employs a frequency hopping transceiver to combat interference and fading. LE also employs two multiple access schemes: Frequency Division Multiple Access (FDMA) used to separate the 40 available PHY channels, 37 of them are used as data channels and the remaining as advertising channels and Time Division Multiple Access (TDMA) in a polling scheme that is used when one device transmits a packet at a predetermined time and a corresponding device responds with a packet after a predetermined interval.

The PHY channels are sub-divided into time units known as events and these can be of two types according to which type of channel they belong, either advertising events or data events.
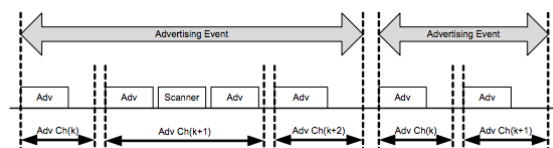
Figure 2.3: Advertising event

Advertising events: There are three roles that can be used to describe a device in function of their utilization of the channel: **advertisers**, are those that transmit advertising packets; **scanners** are devices that receive advertising packets without the intention of connecting with the advertising device; **initiators** are devices that listen for connectable advertising packets in order to later initiate a connection. Transmissions in the advertising channels occur in advertising events which always start with an advertiser sending a packet. Depending on the type of advertising packet, a scanner device may make a request to the advertiser which may be followed by a response from the advertiser, always

on the same advertising PHY channel. The advertising PHY channel changes when the advertiser sends a new advertising packet. An advertising event can be terminated whenever the advertiser wants and when a new advertising event is created it will occur in the first advertising PHY channel. The whole process can be visualized in 2.3.

Figure 2.4: Connection event

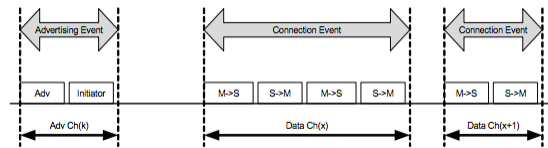**Connection events:** When an advertiser is using a connectable advertising event an initiator may request a connection on the same PHY channel. If the advertiser accepts the connection request, the advertising event ends and a connection event starts in order to establish the connection. Once it's established the initiator takes the master role and the advertised, the slave role. These events are used to transmit data between eachother and they always begin with a message from the master. During a connection event master and slave alternate send data packets on the same packet. The master is responsible for ending the end whenever he pleases and for the creation of new event channel hopping is required. The whole connection event can be visualized in 2.4.

2.1.3.A LE Piconet Topology
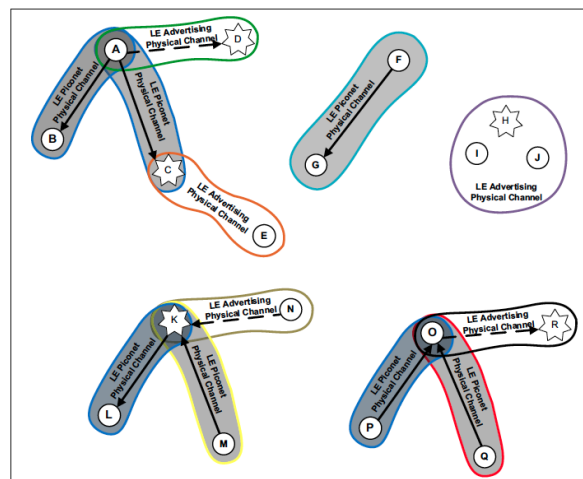
Figure 2.5: Examples of LE topology

As opposed to regular Bluetooth piconets, in LE, slaves can't share a PHY channel and as such each must have his own PHY channel to communicate with a master device. In order to best understand 2.5, solid arrows always point from master to slave, dashed arrows indicate a connection initiation where the arrow points form the initatior to the advertised using a connection event and devices that are advertising are indicated with a star. With these notes the different types of topologies can be analyzed:

- In piconet A, that which contains device A, there are multiple types of topologies such as , device A having connections with multiple slaves and initiating a new one with device D which was advertising. It is also worth noting that the device E is functioning as a scanner listening to the advertiser device C.

- In piconet F there is a simple master slave connection with device F as master and G as slave.

- In Group H there are more than two devices in a single PHY channel, such thing occurs since multiple devices can listen for advertisements on the same channel. In this case device H is functioning as an advertiser while I and J are scanners.

- In scatternet K there is an example where device K functions as master in the conenction with device L and as a slave in the connection with device M, at the same time.

- In scatternet O there is an example where device O is functioning as a slave in both his connections with devices P and Q but it is still capable of forming a connection with R, where O will be the master.

2.1.3.B   Operational Procedures

The most common operational mode of a Bluetooth device is when he is connected and exchanging data with another Bluetooth device. Since Bluetooth is an ad-hoc wireless communications technology, i.e. decentralized type of wireless network, there are a number of operational procedures that enable piconets to be formed so that the subsequent communications can take place.

Device Filtering Procedure Method used by controllers to reduce the number of devices requiring communication responses through the use of a "white list" located in the Link Layer that enumerates the devices that are allowed to communicate with the local device. This procedure allows the device reduce power consuption since it reduces the number of transmitions that it needs to make.

Advertising Procedure An advertiser utilizes this procedure to perform unidirectional broadcasts to devices in the vicinity. The broadcast occurs without any need of connections and can be utilized to establish connections with nearby devices or to simple broadcast information to nearby scanner devices. This procedure includes the operations already described in advertising events in 2.1.3.

Scanning Procedure A scanner device utilizes this procedure to listen to unidirectional broadcasts of user data sent by advertising devices. It is also capable of requesting aditional user data by making a scan request as an answer on the same PHY channel of the first broadcast. This procedure can be utilized while the device is connected to other LE devices for as long as its connections requeriments are maintained.

Discovering Procedure Bluetooth devices use the advertising procedure and scanning procedure to discover nearby devices, or to be discovered by devices in a given area, as such the discovery

procedure is asymmetrical. A Bluetooth device that tries to find other devices in the vicinity can be called as a discovering device and will listen for devices advertising scannable advertising events. Devices that are available to be found and actively broadcast scanable advertising events are called discoverable devices.

Connecting Procedure The connecting procedure is asymmetrical as it requires one of the devices to be utilyze the advertising procedure and the other one the scanning procedure. The advertising procudure has the capability of being targeted which allows only the chosen device to respond. The scanning procedure also has the capability of being target if the device discovers an advertising device and from there on out only listens for its advertisings. Upon receiving a connectable advertising event, it can initiaite the connection by answering with a connection request.

[Connected Mode] Once the Connecting procedure is over the devices are phyically connected to eachother withit a piconet. While in connected mode there is the possibility of changing the connection's properties such as data packet's length and for the device to utilyze advertising,scanning or discovery procedures.

acro! (**acro!**)

acro! (**acro!**)

acro!

acro!

acro!s

2.2 Indoor Technologies

When looking at the state of indoor positioning systems, it's clear that there isn't one technology that is better than all of the others. As so it's important to look at each of the possible technologies individually and assess its benefits and drawbacks as well as their performance.

In this chapter many existant indoor positioning technologies are analysed. The most pertinent ones, RFID, Wi-Fi, Infrared and UWB, are explained in a more detailed manner in subsections 2.4.1, 2.2.2, 2.2.3 and **??** respectively, while less utilized technologies are described in subsection 2.2.5. For each of the present technologies a description is provided about their nature, tags and pros and cons, all of which is complemented with at least one existant system that makes use of the specific technology being described.

2.2.1 RFID

RFID is a technology for storing and retrieving data through electromagnetic transmission to an RF compatible integrated circuit. A RFID system is composed by three components: readers, tags and the communication between both. The reader is capable of reading the data that is being emitted from RFID tags via radio waves and the data usually consists of the tag's unique identification number

which can be related to the tag's available position information in order to obtain the user's position. This communication is achieved by having a well-defined radio frequency and protocol which allows for reading and transmitting data. The RFID tags can be of two types: active or passive.

Active tags are small transcievers equiped with an internal battery, which makes them heavier and more costly while allowing for longer detection ranges when compared to their counter-parts. These tags are suited for identification of important units moving through rough processes or positioning in system where location estimation is often carried out through fingerprinting on Received Signal Strength Indicator (RSSI). Passive tags are operated without the need of a battery since they are capable of receiving enough energy in the form of radio frequency waves from nearby RFID scanners in order to transmit back the answers. These tags are used to replace the barcode technology since they are much lighter, smaller and less expensive than the active tags which allows for a relative inexpensive installation and low maintenance caused by not having batteries. One of its drawbacks is that their range is very limited, circa 2 meters, which demands for higher density of tag deployment.

RFID's biggest advantages are the non required Line-of-Sight (LOS) characteristics, their capability of working at high speeds and their relative low cost. As such this technology is often used for tracking objects in automobile assembly industry or warehouse management and tracking of people or animals. One of its most relevant projects is the SpotON [5], a tagging technology for three dimensional location sensing based on radio signal strength analysis. The tags used are custom devices that operate either standalone or as a plug in card enabling larger devices tot ake advantage of location-sensing technology. They are low power, small and capable of being accurate while having the computing capacity for relevant tasks such as caching, authentication, among others. SpotON tags utilize the received RSSI as a metric for obtaining inter-tag distance. Another important project using RFID is LANDMARC which utilizes active tags to produce a location sensing system for locating objects inside buildings. Its objective was to demonstrate that active tags can infact be viable and cost-efficient for indoor location sensing. One of the problems found was that the hardware wasn't capable of providing RSSI readings, as such the used readers scan through eight discrete power levels in order to estimate the RSSI. This scanning comes at the cost of a significant time period. By placing the readers in known positions, the area that is being analyzed can be divided into sub-regions with each being identified by the subset of readers that cover it. Given an RFID tag, based on the subset of readers that can detect it, the system is capable of associating the tag with a known sub-region. LANDMARC increased the accuracy without placing more readers by employing extra fixed location reference tags for location calibration.

2.2.2 WLAN / Wi-Fi

Wireless Local Area Network (WLAN)is a technology that can be used to estimate the location of a mobile user that resides inside the network. Nowadays Wi-Fi positioning systems have become the most widespread approach for indoor location systems since WLAN acess points are readily available in many indoor environments and any Wi-Fi compatible device (smartphones, laptops,tablets) can be located without the need of installing extra software or manipulating the hardware. Its popularity is

also due to its range of 100 to 50 meters, which is better than RFID and BLE's range, and since LOS isn't required. One issue of WLAN signals is that they suffer attenuation from static environment such as walls and movement of furniture and doors. In these kind of systems position computation is obtained through TOA, AOA, RSS, and CSI, which are properly analyzed in section 2.3, with multiple existing projects for each one of the existant methods. The most widely used is the RSSI, which suffers from severe multipath effects leading to propagation model failures and as such inaccuracy in distance measurement. With these problems in mind a technique called RSSI-based fingerprinting is often used in order to improve performance. Most recently an alternative to RSSI has been researched called Channel State Information (CSI). CSI is widely available on commercial products and it represents the channel conditions over individual OFDM subcarriers across the PHY layer. One of the improvements is that instead of obtaining one RSSI value per packet, multiple CSI values can be obtained from multiple subcarriers at a time. FILA [6] was a project that attempted to use CSI for locating targets in complicated indoor environments where RSSI wasn't reliable due to multipath. This system is capable of extracting the LOS path for distance calculating through time-domain multipath mitigation and frequency-domain fading compensation and with a simple trilateration calculation they were able to achieve a much better performance than with RSSI for these kind of scenarios.

2.2.3 Infrared

Infrared (IR) systems are one of the most common position system that utilize wireless technology that has been used to track objects or people. IR wavelengths are invisible to the human eye under most circumstances, making this technology less intrusive than those which are visible. This technology is widely available in various commom devices such as mobile phones, PDA's and Tv's and requires LOS communication between receiver and transmitter, preferably without interference from strong light sources. These types of system utilize small, lightweight and easily wearable devices which have the downside of having privacy/security issues. One of the most relevant systems based on IR is the Active Badge system which is described in section 2.4. There are three methods of exploiting infrared signals: Through active beacons, infrared imaging or artificial light sources.

The active beacon's approach is the one utilized by the active badge system and it involves placing fixed IR beacons on known positions. The density of deployment of beacons depends on the objective of the system but if the required is a room-based location, i.e. being able to tell in which room a user is located, a beacon per room should be enough.

Infrared imaging, also known as passive IR systems, makes use of sensors operating in the IR spectrum which are capable of obtaining a complete image of the surrounding from thermal emissions. This approach doens't require the deployment of any extra hardware or tag for determining the temperature of objects or people but it does get compromised in the presence of strong radiation from the sun. Some known equipments that utilize this approach are thermal cameras, infrared sensors for motion detection or thermocouples used to measure temperature contact free.

IR systems based on artificial light sources are a good alternative to the ones that operate on the visible spectrum. A very well known example is the microsoft Kinect system which uses continuously-

projected infrared structured light to capture 3D scene information with an infrared camera. This system is capable of tracking a person's movement up to 3.5 meters with a precision of a few centimeters.

2.2.4 Ultra-Wideband

Ultra-Wideband (UWB) is a radio technology aimed at short-range high-bandwidth communication. Its best characteristics are its capacity of being resistant to multipath and to some degree being capable of penetrating building materials, such as concrete and wood, with low power consuption. Both these factors allow UWB to achieve high positioning accuracy while the latter enables to adress the range in non line-of-sight conditions and makes inter-room ranging possible. Being able to penetrate building material creates precision issues due to the increase in data complexity, making data interpretation one of the biggest challenges to be faced. The usual structure of a UWB system has a stimulus radio wave generator and receivers which capture the propagated and scattered waves and it has four types of methods for position calculation. The first one, passive UWB, attemps to track objects or people through signal reflection. This method doesn't require any sort of tag to be carried by the user or attached to the object and requires only at least on emitter and a few listenners to obtain a location. Since the locations of the antennas as known and it is possible to estimate the distance from user to listener through Time of Arrival (ToA) or Time Difference of Arrival (TDoA) multilateration, the user's location can be computed. The remaining methods are Direct Ranging and Fingerprinting. The first one simply requires the users to wear active tags and uses differente measures based on time to compute distances which are then worked by lateration techniques in order to produce the user's location. The second one works like a regular fingerprinting method except that it utilizes Channel Impulse Response (CIR) instead of RSSI. This kind of fingerprinting has the possibility of being more accurate while being usable in non LOS scenarios. On the downside it requires time synchronization. One commercial example of this technology is Ubisense [7], a system capable of tracking active tags equiped with batteries which have a conventional RF transciever and a UWB trasmitter. The system requires a setup deployment of a network of Ubisensors, with fixed positions throughout the area to be covered and networked using Ethernet. Each sensor has a RF transciever and phased array of UWB receivers. These sensors use a combination of TDoA and Angle of Arrival (AoA) techniques to determine the tags location, achieving an accuracy of 15 cm in a typical open environment.

2.2.5 Other systems

Optical indoor positioning systems are systems that use a camera as their only or main input for position estimation. In recent years these types of systems have found an increase in sucess due to the improvements and size reduction of the sensors, the improvements in computational capacities and the constinuos development of image processing algorithms. Optical systems can be described as a moving sensor, for example a smartphone camera, and oftem times a set of static sensors which detect movement and which utilize AoA techniques to estime distances. There are many different types of optical systems, one of them makes use of 3D building models.

This approach removes the need for local infrastructure deployment in the building to be monitored since the usualy required refence nodes are replaced by a digital reference point. As such they are highly scalable with small increases in cost. In general optical systems are capable of achieving high accuracy but they are vulnerable to light conditions, require LOS propagations and are more computationally expensive than other types of systems.

Frequency Modulation (FM) radio is a broadcasting technology that has been incorporated for a long time on smartphones with the intent of listening to music or to the news. This technology was originaly reserved for frequency modulation to convey information over a carrier wave by varying its frequency but nowadays it just refers to any radio wave in the frquency band 88-108 MHz. This analogue radio signal has amazing advantages for urban/indoor location system such as the ability to be received indoor and outdoor, it has a dense coverage in urban areas, available without installing aditional transmitters, low-cost and low-power hardware with simple technology, high received signal power and there are a large number of transmitters which provides good geometry for locationing. One crucial part when utilizing FM is that it doesn't carry any timing information which is critical in range calculation and the fact that as other radio frequency technologies, it suffers from multipath effects and non-LOS signals. An example of FM system was created by et al. [8] which implemented an RSSI fingerprint-based system using FM radios in an office environment. The system's test bed obtained 17 FM channels at each point of the fingerprint and it was capable of achieving a mean accuracy of 3 meters.

Zigbee is an emerging wireless technology standard which provides solution for short and medium range communications and its specialy designed for applications which demand low-power consumption and don't require large data throughput. This technology's signal range coverage can go up to 100 meters in open space, while achieving 20 to 30 meters in indoor environments. Most zigbee-based system utilize RSSI for distance calculation and one of its most relevant disadvantage is the its vulnerability to interferance from a wide range of signal types using the same frequency which can disrupt radio communication. This is caused by Zigbee operating in the unlicensed ISM (industrial, scientific and medical reserved) bands. An example of a Zigbee-based system is the one created by Larrañaga et al. [9] which attempted to locate a mobile node in an indoor environment. Their system consisted of two phases: The first one, calibration, every existant reference zigbee node transmitted message to each of the remaining. In this ways it was possible to work out the relationship between measured RSSI values and geometric distances, allowing to understand the environment moments before attempting a location. The second phase, location, utilizes the data collected and the new data obtained from messages from the mobile user to the refence node to obtain its location. This system was capable of achieved an accuracy with an avarege error of 3 meters.

Ultrasonic system are utilized in indoor positioning by making use of ToA to locate targets. These kind of system make use of ultrasonic transciever to emit and detect signals while recording times of departure and arrival of the signal. Since the signal medium traveling speed is known,

it is possible to use the time difference to compute the distance between emitter and receiver. One of the most famous projects that makes use of this technology is the cricket system which is described in section 2.4.

- [] Hybrid positioning systems are systems which combine several different positioning technologies to determine the location of a user or object. These types of systems make use of different technologies in an attempt to compensate for one's shortcomings through another's strengths. One example of an hybrid system is the solution presented by versus [10] which makes use of Wi-Fi, IR and RF to provide a system capable of displaying real-time locations of people or objects inside a building. By combining these three technologies their were capable of providing a system with different level of accuracy depending on the needs, room-level, bed-level (a fragment of a room) or chair-level (precise positioning).

2.3 Position Techniques

This section's focus is on the available means of obtaining distance measurements from a mobile target to a beacon.

2.3.1 Proximity Detection

Proximity detection is one of the simplest position techniques to implement since its objective isn't to provide a precise position of the target but a symbolic relative location information. The target's position is obtained through the Cell of Origin (CoO) method which relies on a grid of antennas/beacon with a well-known position. When applying this method, if only one beacon is detected by the mobile target then the position provided is equal to the position of the beacon. If more than one beacons are detected by the target, it considers that its position is equal to the position of beacon with the strongest associated signal. In this project, since the objective wasn't to be capable of providing a bluetooth low energy with the best accuracy possible but to prove that the presented architecture was appliable to this type, the CoO method was the chosen one. As such in order to apply room-based accuracy the minimum requirement would be to place a beacon in each existant room. This method can be applied with a better accuracy in mind and doing so depends only on the deployed beacon density. This technique is often implemented in system running IR , RFID and Bluetooth.

2.3.2 Triangulation

The Triangulation techniques makes use of the geometric properties of triangles to determine the location of a mobile target. It can be of two types: lateration, which estimates a target's position by measuring its distance to multiple reference points, and angulation, which obtains the target's position by computing angles relative to multiple reference points. Lateration makes use of ToA, TDoA, Roundtrip Time of Flight (RToF) and RSSI, while angulation utilizes the AoA technique. All the previously mentioned techniques are individually analysed in sections **??**, **??**, **??**, **??** and **??**.

2.3.2.A Time of Arrival (ToA)

ToA-based systems rely on accurate clock synchronization and signal message sent from a mobile target to several receiving beacons. The distance that is to be used in the calculation of the target's position is proportional to the propagation time. As such the message sent from the mobile target is timestamped with its departure time allowing for the receiving beacons to obtained their distance to the target through the transmission time and the associated signal propagation speed. One of the consequences of requiring precise knowledge of transmission start times is that every single device, beacon and mobile target, need to be accurately synchronized with a precise time source which causes this technique to be the most accurate one in indoor environments since it's capable of filtering multi-path effects. On the others hand the disadvantages of using this technique is the synchronization requirements and the additional information that needs to be contained in the sent messages, i.e. timestamps.

2.3.2.B Time Difference of Arrival (TDoA)

TDoA systems attempt to determine the relative position of a mobile target by examining the differences in time at which the signal arrives at multiple beacons. This technique doesn't require clock synchronization with the sender as there is no need for timestamps to obtain its location, making this requirement only present on the receivers. The location is obtain from a transmission with unknown starting time that is received in multiple synchronized receivers which produces multiple TDoA measurmentes. Each difference in arrival times produces a TDoA and consequently a hyperbolic curve on which the target is located. Each intersection of multiple hyperbolic curves represents a possible location of the target, requiring two or more measurments in order to obtain the location on a two dimensional plane.

2.3.2.C Roundtrip Time of Flight (RToF)

This technique obtains distances by measuring the time-of-flight of the signal pulse traveling from the transmitter to the receiver (measuring unit) and back. This solution solves some of the synchronization issues presented by ToA since only the only one of the two nodes records the transmition and arrival times, with the convertion from time to distance being equal to the one applied with ToA. The mechanism of obtaining a time reading is similar to that of a radar, i.e. a signal is sent to which the receiving node replies back to the transmiter. When the response signal is received the roundtrip time is obtained. One issue presented by using this technique is the incapability of knowing the time delay on the receiver between receiving the first signal and sending the response. This unknown delay can be ignore in medium to long-ranged systems if its value is relatively small when compared to the transmission time. In short-ranged system this situation can't be applied and as such this technique isn't suited to be applied.

2.3.2.D RSSI

Received Signal Strength Information (RSSI) is a non-linear signal strength indicator based on signal attenuation that is only usable with radio signals. The convertion of this value to distance is often achieved through estimates of signal path loss due to propagation, although this approach doesn't hold is scenarios where severe multipath effects and shadowing are present.

A technique that is often used with RSSI is the fingerprint method which is the proccess of computing the location of a user by matching its location-dependent signal characteristics to an existing fingerprint database. This method doesn't required any additional hardware on the mobile device or the beacons as well as no time synchronization. This process is divided in two stages: an offline and an online phase. In the offline stage, also called calibration phase, the maps for the fingerprint are set up either empirically in measurement operations or computed analytically through a signal propagation model. For the first option multiple postions are defined on the map. On each of this positions a mobile user captures the signal strengths received from each of the existant beacons. With the fingerprint concluded, begins the online phase, where mobile users are already capable of being tracked. In order to obtain a user's position it must measure the existant signal properties, which are then compared with the fingerprint databse so that a as close as possible match can be found. Position matching is can be achieved through pattern recognition techniques such as K-nearest-neighbours (KNN), support vector machines (SVM), among others. This approach has the drawbacks of being labour intensive and time consuming on the offline phase and the difficulty to maintain and update the fingerprint database in order for it to be in accordance to the current environment. The second drawback is caused by RSSI's sensability to changes in the environment such as dynamic factors (people and doors), diffraction and reflection.

2.3.2.E Angle of Arrival (AoA)

The AoA technique finds the location of the target by intersecting several pairs of angle direction lines. Each of this line is part of the circular radius around a beacon which leads to the mobile target. This technique requires only two beacons for two dimensional and three for three dimensional position estimation, with any extra beacon leading to an increase in accuracy while not requiring any time synchronization. This techniques drawbacks is the increased implementation cost due to the antennas being required to be able to measure angles and its rapid accuracy degradation as the target moves farther away from the existing beacons. This technique is capable of sub-meter accuracy although these types of systems are often limited by shadowing, multipath reflections arriving from missleading directions or by the directivity of the measuring aperture. One example which attempted to tackle AoA's drawbacks was ArrayTrack [11] which presented a multipath supression algorithm capable of removing reflection paths, performance improvements in low density scenarios and parallel processing allowing for faster location estimations. This system was capable of achieving a median accuracy of 23 cm while utilizing custom made access points with 16 antennas. Although successful, the hardware complexity remained an issue making this system inpractical.

2.3.3 Dead Reckoning

Dead Reckoning (DR) is the process of estimating the target's current position through the last determined position incremented by known or estimated speeds over elapsed time. This technique has the advantage of providing autonomous positioning capacities. DR biggest drawback is that the inaccuracy of the process is cumulative, as such the deviation in the position estimation grows with time. This issue can be aggravated by disruptive motion such as sidestepping, back-stepping or sharp turns which produce scaling errors leading to a bigger accurary errors. Due to DR's issues it's often accompanied by another technology in order to correct the inertial drift. A common practice is the usage of GPS,which it doesn't function in indoor environments and as such many different combanitions have been created in order to tackle this issue. Fischer et al. [12] made use of Ultrasound beacons as landmarks to provide better accuracy and less heading errors. In their work they stated the existance of two types of errors: heading errors, which are relative to the direction in which the user is heading, and distance errors. The work was targeted for rescue team first responders and required the users to drop ultrasonic beacons as they advance through the building.

2.4 Related work

Active Badge

In 1992 the Active Badge system [13] was presented as an infrared solution capable of provided room-based position tracking. The system has been designed to make use of "active badge" beacons, which can be visualized in figure 2.6 in the form of ID cards, a tag equiped with an IR LED that emitted a unique code for approximately a tenth of a second every 15 seconds.

Figure 2.6: Active badge's tags (Ref [14])

http://www.cl.cam.ac.uk/research/dtg/attarchive/thebadge.html - image ref

The decision to utilize IR was due to how small and cheap the emitters and detectors are, being capable of operating within a 6 meter range and because IR signals aren't capable of traveling through walls. The signal frequency has two major effects of the system, the first being its impact on the energy consuption of the tags, with such a small frequency allowing for long periods of work on a single battery and the second being its impact on user detection. For the used signal duration and frequency there is a chance of 1/150 for two signals to collide, which leads to a good probability that for a small number of beacons, all will be detected. One downside of such a small frequency signal is that the location of a badge can only be known, at best, to a 15 second granularity.

The position of a user is obtained through the implementation of a network of sensors which act as receivers, listening to badge transmitions, and then forward the obtained information to the master station. The master station is responsible for polling all the sensors on the network, store sighted badges into a database with its associated time, position and ID, data processing and data display. The accuracy of the system is room-based by making use of CoO and the properties of IR. A beacon

in each room would make it so that each beacon is capable of detecting any badges in its room.

One of the issues that surfaced with this system were privacy issues. Due to the system's nature, the position of each badge is known in a centralized station, with the only available option for people who don't wish to be tracked, to disable their tag. Another privacy issue was the security of the system's data with needed improvements to control access to data [15].

Active Bat

In 2001 the Active bat system [16]was introduced, a system capable of tracking various object, each tagged by attaching small wireless transmitters called bats. The system's architecture is composed of small devices named bats, which are to be carried by the objects or people to be tracked, a network of Ultrasound (US) receiver units and several base stations. The receiver network and a deployed bat can be seen on figure
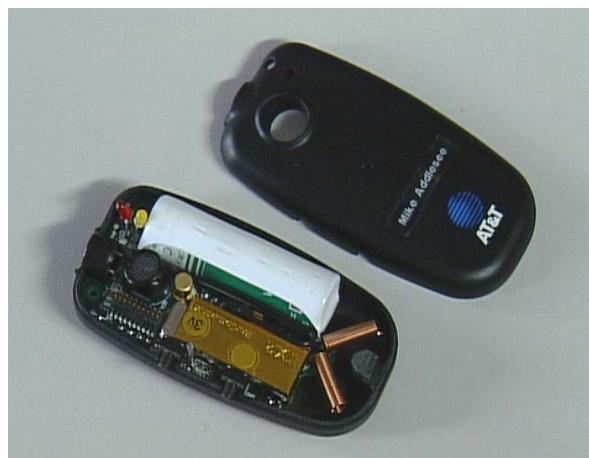

Figure 2.7: Active bat (Ref [17])

A bat, which can be seen in figure 2.7, consisted of a radio transciever, controlling logic and a ultrasonic transducer, with each having an associated globally unique ID. A Base station periodically transmits a radio message containing a single unique ID, making it so that the ID's associated bat emits a short pulse of US. At the same time, the ultrasound receivers present in the rooms covered by the base station that emitted the radio signal are reset through the wired network. From this point on, the receivers monitor for the expected US signal while recording the time spent waiting in order to obtain the signal's ToA. With a known speed of sound in air, which can be estimated from the ambient temperature, the ToA can be converted into bat-receiver distance.

The mobile target's position can be obtained through multilateration, in the three dimensional space, if three or more non-collinear receivers' distances are known. This method's accuracy is highly dependent on the distance measurement's accuracy. Distance measurement is affected by signal reflections on objects present in the environment, a problem that was correct by the use of a statistical outlier rejection algorithm. One other issue is the reverberations of the initial signal, which are required to die out before initiating another distance measurement in order to ensure that the incoming US signals are from the correct bat. As such the measurement process is devided into timeslots, with each being usable to locate one and only one bat.

The existant system is capable of being improved in order to also provide the target's orientation. The first option is to place several bats at known points of the rigid object and finding their positions on the 3D space. In cases where multiple bat deployment isn't feasible, if the rigid object is opaque to ultrasound, one single tag might be enough to estime the objects orientation since any cast signal leaves a shadow on the object [18].

The latest version of the bat included a sensitive motion detector that allowed it to tell the base stations wheter it was moving or stationary. Since the base station doesn't require to repeatedly determine the location of a stationary object, the system places these bats into a low-power sleep state which is only removed once the bat stats moving. This implementation allowed for extra power savings while freing up location-update opportunities for other bats [19].

This system's architecture, much like the Active badge's presented in 2.4, is tightly controlled and centralized. As such it also incurs into the same provacy issues from the active badge system. Another problem created by this system's technique is the requirement of large numbers of receivers across the ceiling and their placements which require sentitve alignments.

Radar

In 2001 the RADAR system was introduced as the first Wi-Fi signal-strength based indoor positioning system [20]. The system is Radio Frequency (RF)-based and its capable of locating and tracking users inside buildings. Radar makes use of signal-strength information obtained through a fingerprint method, presented in subsection 2.3.2.D, to trinagulate the user's coordinates. The system's functions in two phases: the data collection phase, where the data is gathered in order to later construct and validate models for signal propagation, which are to be used in the real-time phase to infer user's location. In the offline phase, the type of data collected is the signal strength utilizing the methodology already described for the fingerprint method.

Radar's experiments showed RSSI's problems relative to value fluctuation dependent on the user's orientation. This happens due to the existance or not of LOS between antenna and base station depending on the orientation, since the user's body may form an obstruction. As such the user's direction was also recorded in the offline phase.

Data processing involve computing the mean, standard deviation and median of RSSI for each of the used base stations (three in total) and each combination of x,y and direction. In addition, a building layout information was created which included room and base station's coordinates and the number of walls that obstructed the direct line between the base stations and each of the positions where data was collected. With all this information an accurate signal propagation modal was built.

The basic approach used to obtain a user's location was triangulation, which given a set of RSSI measurements at each base station, the user's location is guessed to be the one that best matches the observed data. In addition to this basic strategy, two others approaches were analyzed: empirical and signal propagation methods.

For the first method many variations on the data was studied such as: The number of best matching values used (K-nearest neighbours (KNN)), with results showing that the benefits of averaging between multiple neighbours isn't very relevant even for small values of k as in this case it doesn't

mean that there aren't k physical distinct points. Other factors were studied such as the impact of the number of samples collected or the number of data points and the impact of the user orientation, with the most relevant being the latter, having shown the relevance of collecting data for multiple directions. In general the empirical method was capable of estimating the user's location with high accuracy, obtaining a mediam error distance between 2 and 3 meters, and with its main drawback being the required effort for building the data set for each physical area of interest. Another issue is the requirement to remake the data collection phase whenever a base stations is moved or there are heavy changes in the environment.

The signal propagation model comes as an alternative to the empirical method for constructing the fingerprint. This method makes use of a propagation model for the signal to generate a set of theoretically-computed signal strength data, similar to the one physically collected. The performance of this method is correlated to the how well the used model is capable of correctly describe the signal. The system's chosen propagation model was Wall Attenuation Factor model (WAF) which takes into consideration obstacles between transmitter and receiver. This model provides a more reasonable way of obtaining data, since it doesn't require detailed and costly measurements. When compared to the empirical method, it was capable of achieving a mean error distance of 4.5 meters, that although it isn't as accurate it can be considerate as a solution when analysing its benefits.

Cricket

The Cricket system [21]was developed by the Massachusetts Institute of Technology (MIT) in 2005 and managed to tackle some of the problems existant in the previously mentioned systems. The system makes use of nodes, small hardware platforms, consisting of a RF transceiver, a microcontroller and hardware capable of generating and receiving ultrasonic signals. There are two types of nodes: beacons, which are fixed reference points attached to the ceiling or walls of the building, and receivers, called listeners, which are attached to the objects that need to be tracked. Each beacon periodically transmits a RF signal message containing beacon specific information, such as the beacon's unique ID, its coordinates and the physical space associated to the beacon. Whenever a RF signal is transmitted, an ultrasonic pulse, which doesn't contain any data, is also emitted thus enabling listeners to measure their distance to the beacons by using the time difference of arrival times of the RF and ultrasonic signals. Each listener utilizes the RF signal's beacon information alongside the obtain distances to beacons to compute their space position and orientation.

When a beacon is deployed it doesn't know its exact position, only a human-readable string which describes its location. In order to compute the recently deployed beacon's position a listener is attached to a roaming device in order to collect distances from the beacons to itself. These distances are used to compute inter-beacon distances, which, when in high enough number, are capable of uniquely define how beacons are located in respect to eachother. With this information it is then possible to obtain the beacon's coordinates.

The utilized method for computing distances doesn't require listeners to actively transmit messages which permits cricket to perform well independently to the number of users. This active-beacon passive-listener architecture makes it so that the position of the user isn't tracket by the system thus

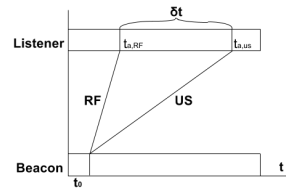solving the user privacy that were present in the remaining projects.

Figure 2.8: Cricket's TDoA representation

Distance measurement is computed through TDoA using both RF and US signals and it can be visualized in figure 2.8. Since the velocity of the RF signal is much higher than that of the US signal and when considering a direction, the US signal lags behind when compared to the other. As such, whenever a listener receives a RF signal, it measures the time is takes until the US signal arrives, denominated $\delta T. With knowledge of the speeds of sound and light, the distance between beacon and listener can be obtained from:$

$$\delta t = \frac{d}{v_{US}} - \frac{d}{v_{RF}}$$

This approach to distance computation is vulnerable to a certain amount of factors such as: Environmental factors since the velocity of sound depends on factors such as temperature, humidity and atmospheric pressure; Lack of LOS since in these scenarios there is no LOS between the beacon and the listeners, the US signal may reach the listener after it has reflected on a surface. Reflection and refraction cause the signal to travel a longer distance than the direct path; Errors in detecting US due to the threshold-based approach to detect the signal; TDoA associated errors, which are associated to errors from time measurement and errors from detecting the RF signal.

In terms of performance, Cricket was capable of a distance measurement accuracy of 4-5 cm within a 80º cone from a given beacon, position accuracy of 10-12 cm and an orientation accuracy of 3º - 5º.

BLE systems

When looking at what's possible to achieve using the BLE technology there is the example of Apple's creation iBeacon [?] which was presented in 2013 with the porpuse of implementing proximity sensing systems. The device is capable of playing on the broadcaster role and as such its objective is to send nearby compatible receivers certain information. Some examples of application are to track customers or trigger location-based actions on devices such as push notifications or checking in on social media, with pratical cases such as the usage of iBeacons by McDonalds to offer special offers to their customers in their fast-food stores. An indoor location system utilizing this technology was presented by Jingjing Yang et al [?], where these devices were used to indicate a pacient of his

whereabouts through the proximity sensing proprieties and this information was later transfered over to a server in order to give clients a variaty of different services, from pacient counting, to nearby department's information and offer indoor guidance to the nearest available bed.

*When utilizing BLE for indoor location the usual metric used to calculate distances is the RSSI. This metric withint the context of bluetooth brings to surface several issues such as the fact that RSSI as a metric is very accurate only when the target is within a meter of the beacon, since the value decreases as the inverse of the square of the distance to the beacon . As such when developing solutions for indoor location that require system with high accuracy capable of tracking moving objects, the usage of RSSI can't be utilized without further work. Faragher et al [**?**] tackled one of the techniques used to improve BLE system's accuracy, fingerprinting, by verifying the effects caused by the device deployment density within the required location. This experiment also puts into evidence one of the downsides of the bluetooth technology being that its scalability is low, besides requiring higher density in order to increase accuracy, due to their low range any need to increase coverage leads to increased costs.*

*Zonith [**?**] introduced a bluetooth based location system with the objective of tracking the position of workers in dangerous environments. Any device registered in the zonith implemented network would be continuously tracked and accounted for in each of the system's functionalities such as, sounding an alarm whenever a lone worker doesn't move or responde within a time interval (Lone worker protection) or providing a quick an precise location of any worker that has requested for help. This system's installation requires planing of the best locations to place the beacons and number required of beacons in order to be able to provide enough courage and make sure the system provides the required quality.*

BLE IMPROVEMENTS.

2005 - http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.99.3970rep=rep1type=pdf for RSSI problems

2015 - http://icact.org/upload/2015/0525/20150525$_{final paper.pdf}-Analysis of density's effect on accuracy$

2016 - https://www.researchgate.net/profile/Jeewoong$_{Park}/publication/305043911_{Using_{B}IM_{G}eometric properties_{f}}$ $based_{I}ndoor_{L}ocation_{T}racking/links/577fc71908ae9485a439ae6b.pdf-BIM to help BLE$

http://www.cl.cam.ac.uk/ rmf25/papers/BLE.pdf - An Analysis of the Accuracy of Bluetooth Low Energy for Indoor Positioning Applications; ——RSSI fluctuation, fingerprinting and multipath mitigation

http://airccj.org/CSCP/vol5/csit54714.pdf - Accelerometer para filtrar resultados

Dietrich et al. [2004] deploy a moving Bluetooth-enabled mobile device as the transmitter, along with a dedicated correlation IC and microcontroller as two receivers. The position is calculated by TDOA measurement to achieve meter-level accuracy. Chen et al. [2010] present an inquiry-based locating approach using Bluetooth RSS measurements.

Dietrich, G. Fischer, and F. Winkler. 2004. Bluetooth indoor localization system. In Proceedings of the 1st Workshop on Positioning, Navigation and Communication (WPNC'04).

Chen, L. Pei, and J. Liu. 2010. Using inquiry-based Bluetooth RSSI probability distributions for indoor positioning. Journal of Global Positioning Systems 9, 2 (2010), 122–130.

http://s3.amazonaws.com/academia.edu.documents/30924074/JoGPS$_v$9n2p122−130.pdf?AWSAccessKeyId =
$AKIAJ56TQJRTWSMTNPEAExpires = 1481741330Signature = D01oLIJ$

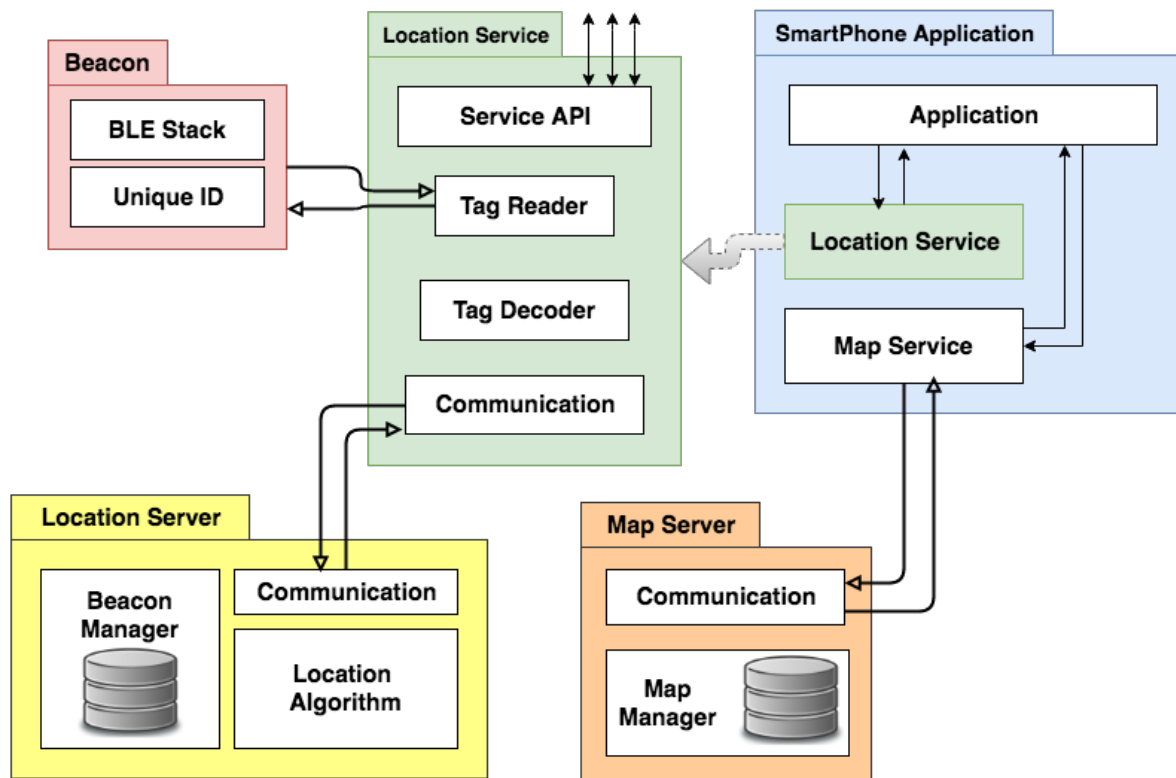### 2.4.1   RFID

3

Architecture

Contents

Figure 3.1: Generic System's Architecture

This chapter gives an overview of the state of the art of Indoor positining solutions. The Bluetooth Low Energy (BLE)'s architecture and functionality is analyzed in section 2.1, while section 2.2 overviews the other existing technologies. The most common techniques utilized for position computation along side examples which make use of them are explained in section 2.3. Finnally on section 2.4 analyzes the most projects that had the most relevance in the field and the existing work related to BLE.

3.1 Generic Architecture

The solution presented in this paper was made with the objective of creating a generic indoor location system capable of being implemented using any existant indoor system created. The generic system's architecture is presented in figure 3.1 and it's divided in 4 parts: beacon, location server, map server and smartphone application.

The beacon represents any form of hardware responsible for providing fixed reference points which are fundamental in calculating a user's position. A beacon needs to be be composed of two structural blocks: The Unique ID, which stores any information crucial to identifying a beacon, and the Hardware specific software component, which contains all the necessary software to accomplish communication with a certain technology.

The location server is divided in three: the Communication block, which is responsible for creating, managing and terminating a connection with the mobile application; the location algorithm, architectural block responsible for applying a certain location algorithm to the data received from the

application in conjuntion with the server's device information in order to obtain a concrete location; and the beacon manager which functions as a database where all the beacon associated with the server are stored.

The map server represents the architectural block responsible for providing the maps associated to the location of user obtained through the location service on the application. As such it requires a communication block which needs to be capable of communication with the map service of the application and takes care of creating, managing and terminating connections, and a map manager which stores the existing maps that are to be transfered to the application.

The smartphone application is divided into three functional blocks: core application, location service and map service. The core application contains the core functionality of the application and is in charge of communicating with the existing services. Communication with the location service allows for requesting the user's location which is then forwarded to the map service, in order to obtain the associated map. The location service is composed by four blocks: the API component through which it communicates with the core of the application; the tag reader which is the functional block responsible for reading a certain type of tags (beacons) and as such its structure will depend on the type of beacon utilized by the service; the tag decoder, functional block responsible of utilizing the information obtained through the tag reader and process it in order to be forwarded to communication block; the communication block which takes care of the creating, managing and terminating connections with a location server.

It might be relevant to analyze some types of indoor location system that could diverge from this architecture, such as camera or Quick Response (QR) code-based systems. These systems would still follow the proposed architecture except for the beacon component which would not be existant and the location service's tag reader block wouldn't need any sort of communication since it would be responsible of utilizing the camera to capture either a fotograph or reading a QR core.

Although figure 3.1 is representative of a system utilizing a single type of technology, the presented solution is scalable, allowing for insertion of additional indoor location systems onto a single architecture. The changes required for implementing such a scenario would be to add one extra layer of complexity on the android application as present on figure 3.2. In this new architecture, the application's core would only communicate with the location manager and the latter would now be responsible of managing through all of the location services and request execution of whichever service would be more suited or available. The location manager would also be required to manage through the existant map services, which may or may not be in same number as the existant location services, and make sure that the data obtained from a certain location service is forwarded to the correct map service which must capable of processing it.
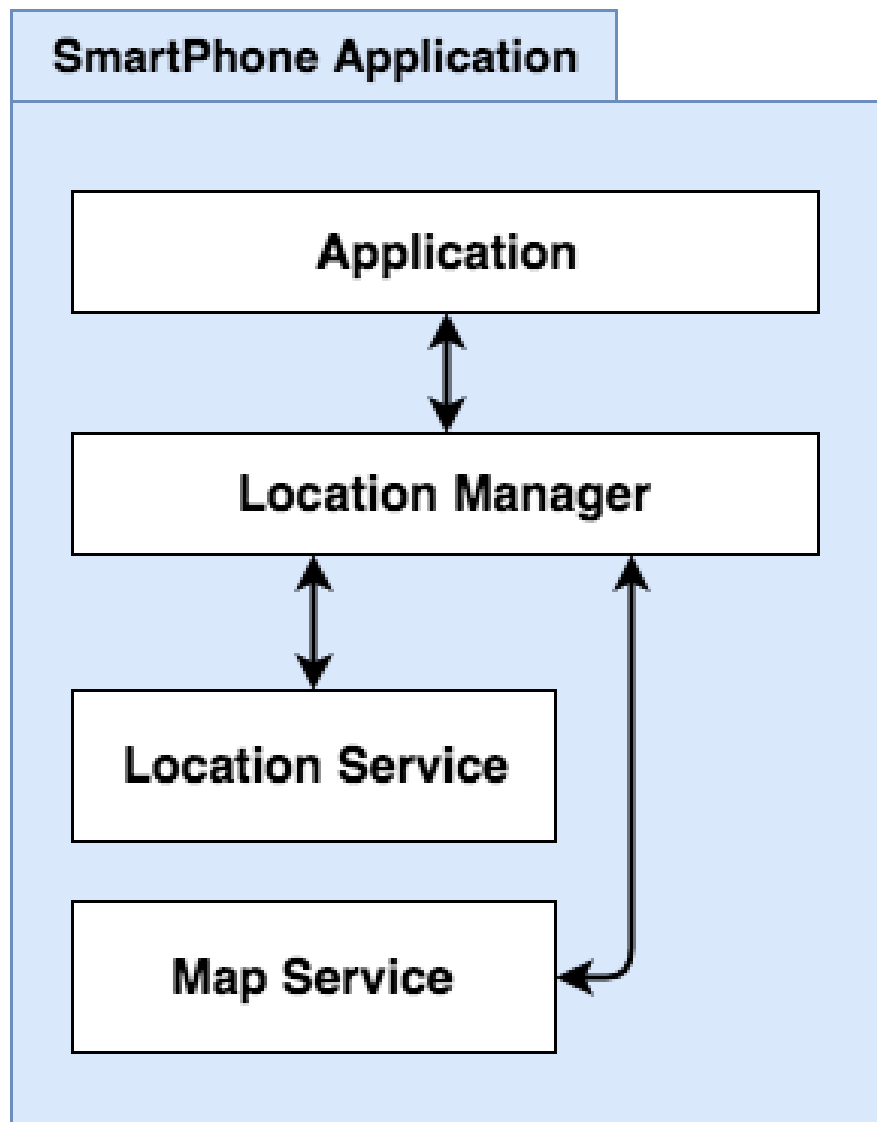
Figure 3.2: Adjustments to the application required for multiple indoor location systems
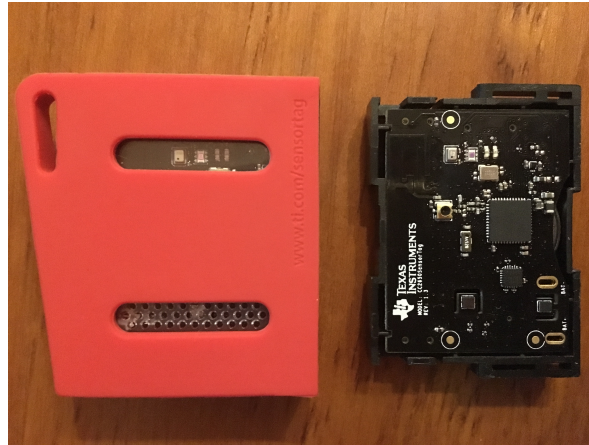
4

Implementation

Contents

Figure 4.1: TI cc2650stk sensortag

The implementation presented in this paper was created by utilizing the generic indoor location system presented in section **??** and applying it with bluetooth low energy. The system's architecture is presented in figure **??** and is divided three parts: the bluetooth low energy device, in section **??** a description of the used technologies and the changes made are present;the server, whose funcionalities and stored information are described in section **??**; and the smartphone application, whose process is described in section **??** alongside figures that show the functional prototype. For each of these parts an explanation will be given, containing a description of each of its components specific to the presented system alongside the requirements for each to work.

This chapter gives an overview of the state of the art of Indoor positining solutions. The Bluetooth Low Energy (BLE)'s architecture and functionality is analyzed in section 2.1, while section 2.2 overviews the other existing technologies. The most common techniques utilized for position computation along side examples which make use of them are explained in section 2.3. Finnally on section 2.4 analyzes the most projects that had the most relevance in the field and the existing work related to BLE.

4.1   BLE beacons

The beacons that were utilized are Texas Instruments CC2650STK devices which can be visualized in figure 4.1. Alongside the device, which comes with a pre-installed bluetooth low energy program capable of giving information on each of its ten sensors through its predefined profiles, there is a texas smartphone application that can connect to a single device and read from its sensors. By using the texas Code Composer Studio (CSS), the pre-defined ble profile existant on the device could be altered. Upon further analysis of the profile, a characteristic was found for which the Universal Unique Identifier (UUID) of the service and the characteristic itself was found and as such this was the one that ended up being used to store the device's owner server's address. Since the device was already set to work as a pheripheral and it now stored the information relevant to the system, there was no need to do further work.

4.2 Server

The webserver was implement in Python 3 programming language. The program implements a simple tcp server capable of receiving multiple request at the same time. Each request starts with information sent from an application which include a pair of MAC address and associated RSSI value for each ble device that the same application found. Afterwards the list of pairs is filtered in order to remove any existant devices that are not present in the server's database of devices.

Each server has a database that includes only ble devices. An entry (description of a device) in this database is composed by the device's mac address, its longitude and latitude and its building, floor and room name. In addition to the database, a server when initiated can store additional location info such as the server's street, number, zipcode, city and country, allowing this information to be transmited to the client in order to offer an additional level of location description to the user. The whole location specific information can be visualised in figure 4.4.

Upon having filtered the initial list of pairs, the Cell of Origin (CoO) technique is applied by verifying which of the devices produced a stronger signal on the receptor. Upon obtaining the closest device an answer is sent to the application containing all of the information associated to the server and the selected device.

- Describe the Database (insert image example of database with a few entries??)

- Mention capability to Insert aditional info, at the moment it displays geocoding on pop up menu in figure 4.4.

4.3 Application

The Smartphone application was developed for Android using the Android Studio IDE. The Application is divided in two primary functional blocks, the Mock location Provider and the Google Maps Integrated Display, as can be visualized in figure **??**.

The Mock Location Provider is implemenented as if it was a Location provider, such as gps. The application functions works as a listener to a Location provider, in this case it listens to the Mock Provider that was implemented. By implementing the whole process of obtaining a location inside a service (the mock provider) , a new level of abstraction is added to the application. As such, whenever the application is signaled to obtain the user's current location, a request is made to the associated location provider and the application only need to listen for the answer that eventualy arrives.

The Mock Location Provider incorporates the first three steps present in figure 4.2, which will now be explored individualy. The first step indicates the gathering of information of the surroundings of the user's device. When a request is made to the provider, a scan for nearby bluetooth low energy devices is made which will put the smartphone in a state of listening for incoming ble advertisement packets for half a second (NEED TO VERIFY VALUE AND JUSTIFY, THERE WAS A PAPER ON THIS TODO). During this scanning period, each time a device is found, the advertisement is registered in a list, which have a duplication prevention mechanism implemented. Once the period is over, the provider has avaliable a list of all the ble devices within range.
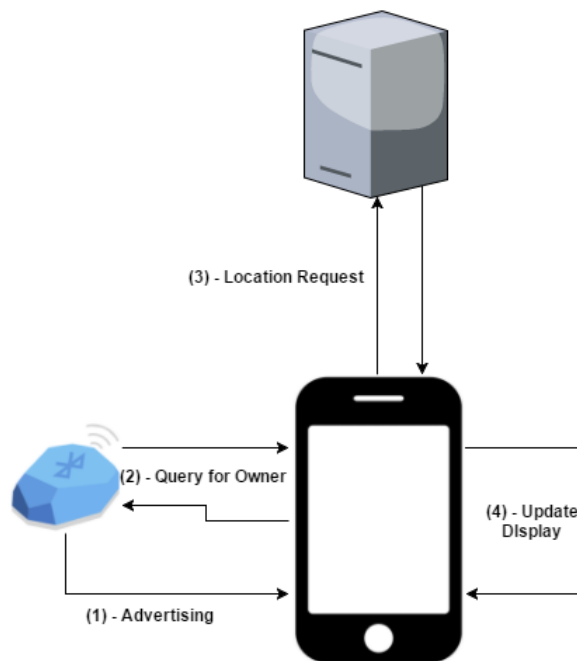
Figure 4.2: Mock Location Provider Workflow

The second step involves taking the created list of devices, obtain a server adress and forward the same list to it. Once the first step is completed, the provider will analyze each entry at a time. For each device the provider will attempt to respond to the caught advertisement packet, resulting in a created connection. Once the connection is created the provider asks for the available services of the paired device. Upon receiving an answer, the list of services is swoop while looking for the service with the wanted UUID. If the device doesn't have the UUID that the provider is looking for, it can assume that the paired ble is not a beacon of our system, as such the connection is terminated. When the provider identifies that the device has the system's UUID, it requests the device to provide the service's existant characteristics. The provider will receive a list composed of the service's characteristics and it will search in it for the system's characteristics UUID, the one which contains the device's server's address. This search has the objective of confirming that the service existant in this device is indeed the one that was implemented for the system and not a device with another service that happened to have the same UUID. For any service outside those that are documented in the Bluetooth Special Interest Group (SIG), who have a specific UUID attached to them, the UUID is generated randomly and as such there is a small chance of collision. Once the wanted characteristic is found, the provider requests the device to read its value and stores the received value in a list. This list will contain the servers of the devices that were found, and for each address there will be a list corresponding to each device , and their corresponding rssi values, from the same owner. In order to quicken the previously described process, the provider keeps in cache the most recent contacted devices. Before attempting a connection, the provider confirms that the device isn't found in cache and when finishing a process, the associated device is inserted into the cache.

When every device has been contacted, a voting system is actioned which will decide from the list of servers which one it will send the collected information to. The voting system uses an exponential

function in order to attribute a weight to each server. INSERT FUNCTION AND EXPLAINATION.

The voting system was implemented with the objective providing a thin security layer by allowing multiple devices of the same server to overcome a single attacker's device which happened to be close to the user. After obtaining each server's values, the one with the highest value is chosen and sent the list with all the devices.

The Third step involves a simple client/server tcp interaction. The application starts off by formulating the message that it will later on send to the server, this message includes all pairs of device mac address and its associated rssi value captured by the application on the first step. Once the message is computed, the application attemps to create a connection with the server at the chosen address at the end of step two. With the connection established, the message is forwarded to the server and the application is put onto blocked state where it awaits for an answer. Upon arrival, the answer received is checked for valid location, its information is process and the connection is terminated. The information contained inside the received message, which was described in section **??**, is then processed into the adequate class capable of storing a geographic location and the same is broadcasted from the mock location provider to its listener.

One of the current limitations of the android API that deals with BLE is that the interface on the smartphone that is used to connect with a device has a fixed timeout time. MIGHT JUST NEED TO BE IMPROVED TODO

The Google Maps Integrated display is implemented using the Google Maps Android API. By using Google Maps it was possible to aliviate the weight on application since there wasn't need implement file transfer of indoor building's maps from each dedicated server to each request, which aliviated the servers aswell since there was no need to store its associated building's maps on it. Managing the maps was something that was aswell fortunately unnecessary and as such all these features were provided by google maps service. By making this development choice, the system as whole became closer to the desired generic approach while making possible for seamless transition between indoor/outdoor maps. The only imposed restriction is related to the addiction of new indoor maps onto the google maps, which is possible and well documented but dependent on a third party.

The Fourth step is called when the application receives a proper location from the request made onto the location provider. With the device's location known, a marker is placed on the map with the obtain coordinates (longitude, latitude), the camera is moved in order to be centralized on the position and fully displaying the indoor level map, and the menu visible on figure **??** is updated with the information that is bundled with the received location. In order to show the correct level on a multi level building, the "floor" information present in the menu is utilized. The API allows for obtaining a list of existant levels on which the maps' camera is focused and as such it's possible to find out to which level the provided locaiton belongs and make so that the application shows it.

The pop-up menu was implemented to demonstrate the capacity of providing additional information associated with each location, be it geo-location taxonomy as it is currently implemented or possibly a description of the located room, an hyperlink of some sort or any other type of data that someone implemented this system would like to provide to its users.
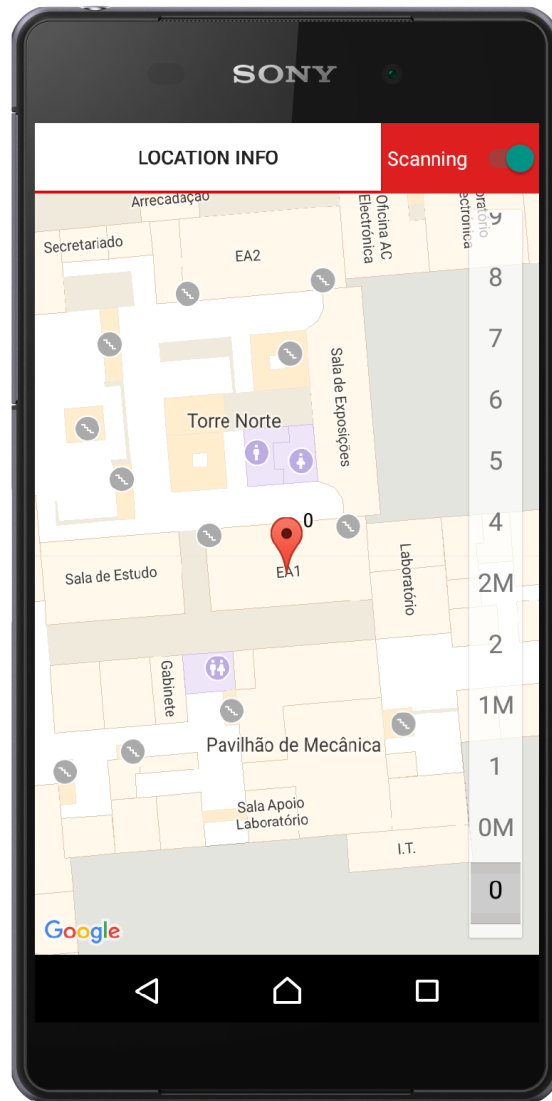
Figure 4.3: Application screen showing a focused location on a room

The final state of the implemented system can be visualized in figure 4.3 and figure 4.4. The first displays the case of obtaining a location, where the marker has been placed and the camera zoomed
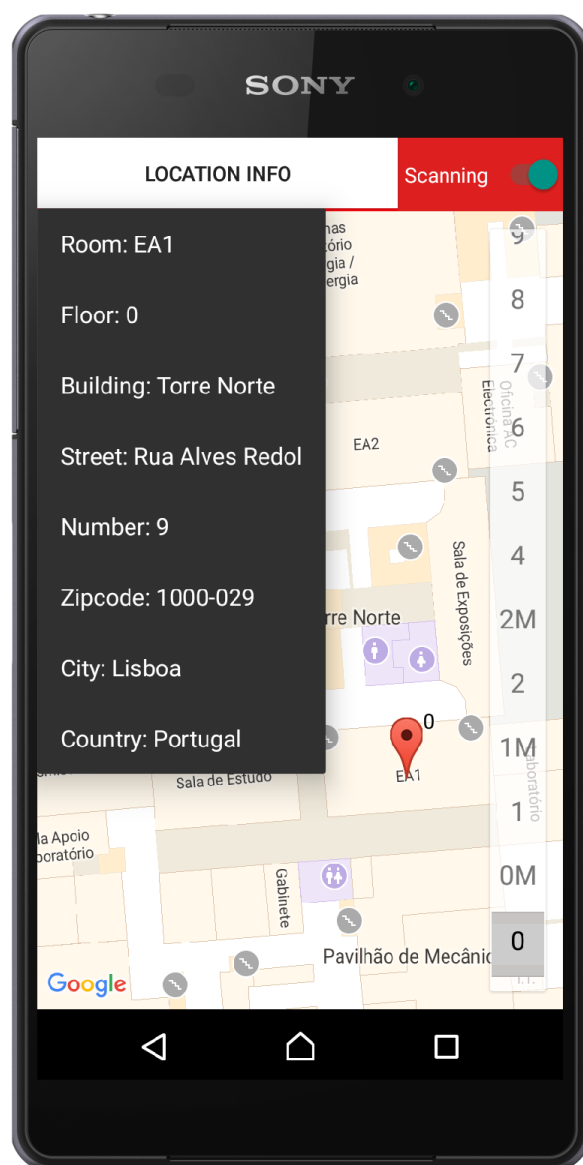
Figure 4.4: Application screen showing additional information of location

5

Conclusions and Future Work

Conclusions Chapter

Bibliography

[1] H. Koyuncu and S. H. Yang, "A survey of indoor positioning and object locating systems."

[2] R. N. Zahid Farid and M. Ismail, "Recent advances in wireless indoor localization techniques and system."

[3] H. Liu, "Survey of wireless indoor positioning techniques and systems."

[4] Y. Y. Jiang Xiao, Zimu Zhou and L. M. Ni, "A survey on wireless indoor localization from the device perspective."

[5] G. B. Jeffrey Hightower and R. Want, "Spoton: An indoor 3d location sensing technology based on rf signal strength," 2000.

[6] Y. Y. M. G. L. M. N. Kaishun Wu, Jiang Xiao, "Fila: Fine-grained indoor localization," IEEE 2012 INFOCOM, 2012.

[7] S. G. Pete Steggles, "The ubisense smart space platform."

[8] A. G. D. Vahideh Moghtadaiee and S. Lim, "Indoor localization using fm radio signals: A finger-printing approach," 2011.

[9] J.-M. L.-G. Janire Larranaga, Leire Muguira and J.-I. Vazquez, "An environment adaptive zigbee-based indoor positioning algorithm," 2010.

[10] [Online]. Available: http://www.versustech.com/rtls-technology/

[11] J. Xiong and K. Jamieson, "Arraytrack: A fine-grained indoor location system," 2013.

[12] M. H. Carl Fischer, Kavitha Muthukrishnan and H. Gellersen, "Ultrasound-aided pedestrian dead reckoning for indoor navigation," 2008.

[13] [Online]. Available: http://www.cl.cam.ac.uk/research/dtg/attarchive/ab.html

[14] [Online]. Available: http://www.cl.cam.ac.uk/research/dtg/attarchive/thebadge.html

[15] V. F. Roy Want, Andy Hopper and J. Gibbons, "The active badge location system," Proceedings of the Fifth Annual ACM/IEEE International Conference on Mobile Computing and Networking, pp. 59–68, August 1992.

[16] [Online]. Available: http://www.cl.cam.ac.uk/research/dtg/attarchive/bat/

[17] [Online]. Available: http://www.cl.cam.ac.uk/research/dtg/attarchive/bat/flatBatInside.jpg

[18] P. S. A. W. Andy Harter, Andy Hopper and P. Webster, "The anatomy of a context-aware application," 199.

[19] S. H. J. N. P. S. A. W. A. H. Mike Addlesee, Rupert Curwen, "Implementing a sentient computing system," IEEE Computer Magazine, vol. 34, no. 8, pp. 50–56, August 2001.

[20] [Online]. Available: https://www.microsoft.com/en-us/research/project/radar/

[21] N. B. Priyantha, "The cricket indoor location system," Ph.D. dissertation, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, June 2005.

A

Title of AppendixA