

## **BLE supported indoor location**

Subtitle

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***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)



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# Abbreviations

**GPS** Global 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

**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

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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 Global 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 incorporated GPS system. This passage occurred 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 satellite, 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 electromagnetic 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 challenges such as: small space dimension, which reinforces 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 deployed site-wise and as such have a much smaller range and are capable of at least providing a much clearer line of sight between deployed 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 deployed 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 antennas to overcome GPS's indoor issues, RFID , Wireless Local Area Network (LAN)

and Bluetooth among others, allowing even for hybrid 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 sparked the research for different technologies capable of filling the hole. As such in the last fifteen years many indoor systems have been created which attempted to solve the problem using one or more technologies, each with their strengths and weaknesses.

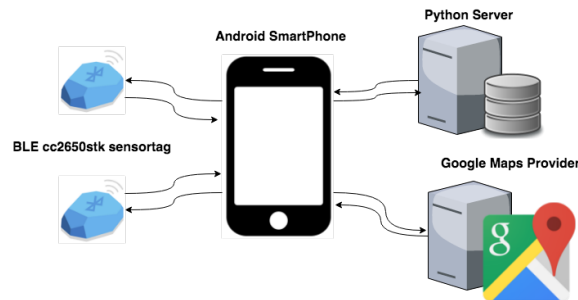
With the advancement of smartphones they are now capable of providing many more tools that can be useful for indoor location such as GPS, Wi-Fi, GSM, camera, FM radio, Bluetooth and microphone. Beside these tools, nowadays they even have inertial sensors such as accelerometers, gyroscopes or digital compasses which, together with ones that were previously mentioned, provide a wide variety 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 existing 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 existing 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 achieve the project's requirements.

This occurrence has led to a need to register the state of the indoor location which has been fulfilled by all the existing surveys on the existing technologies [4? ], which gather up all the existing 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 focusing on existing projects to compare their performances [3]. Another relevant aspect that has been surveyed is the existing 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 existing systems. With all the existing work related to improving a certain technology's performance there was an higher interest in on the possibility of integrating multiple existing 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 utilizes 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 responsibilities while chapter 4 demonstrates the implemented BLE solution based on the previously presented generic architecture.



# 2

## A Chapter

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*Present the chapter content.*

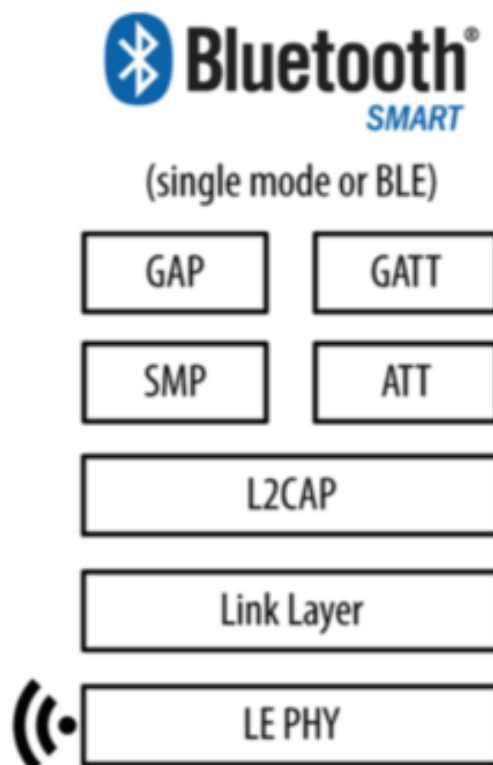
## 2.1 Bluetooth Low Energy

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 consumption 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 stood 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 access to the radio medium, this means access to the PHY channels. It has two purposes, 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 functionality 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 function 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 support 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 functions as the initiator for all of them. These connections are all made with Peripheral devices and its controller must support the master role in a connection and allow for more complex functions, 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 functionalities 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

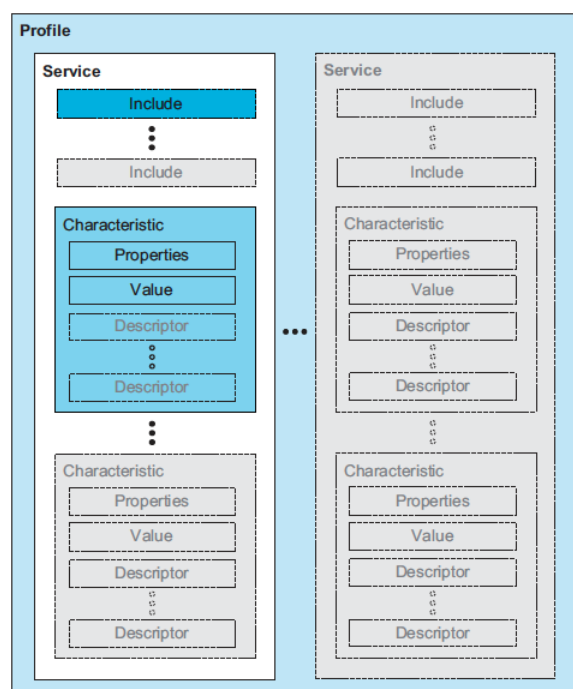
Bluetooth profiles defines the required functionalities of each layer, from the PHY to the L2CAP layer, as well as the the vertical interactions between layers and P2P interactions between device and a specific layer. Since a profile also defines application behaviour and data formats, we can say that 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 individually:

**Service:** A profile is composed by one or more services. CITAÇÃO 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 functionalities of a device, or secondary, 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 describe 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.

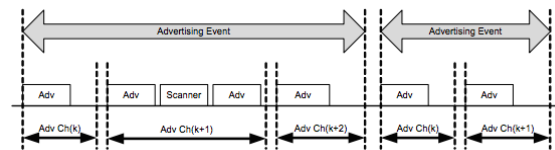


**Figure 2.2:** Gatt-based profile hierarchy

### 2.1.3 Communication Topology and Operation

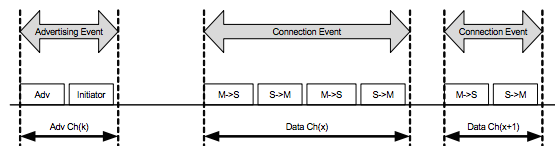
The LE radio operates at the 2.4GHz band and employs a frequency hopping transceiver to combat interference and fading. LE also employs two multiple access schemes: Frequency Division Multiple Access (FDMA) used to separate the 40 available PHY channels, 37 of them are used as data channels and the remaining 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

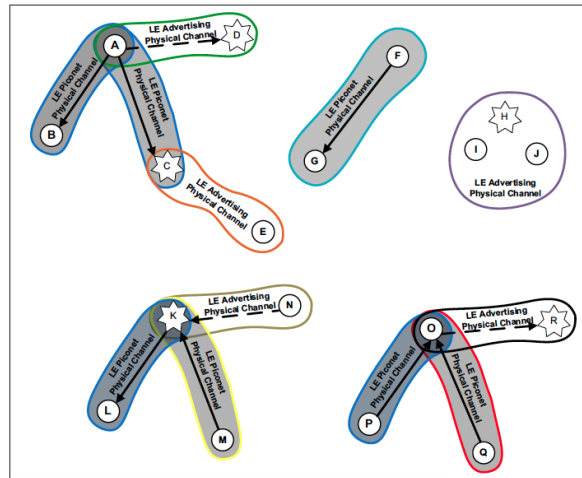


Figure 2.5: Examples of LE topology

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 from the initiator 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 connection 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 tech-

nology, 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 consumption since it reduces the number of transmissions 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 simply 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 additional 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 requirements 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 scannable advertising events are called discoverable devices.

**Connecting Procedure** The connecting procedure is asymmetrical as it requires one of the devices to be utilize the advertising procedure and the other one the scanning procedure. The advertising procedure 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 advertisements. Upon receiving a connectable advertising event, it can initiate the connection by answering with a connection request.

[Connected Mode] Once the Connecting procedure is over the devices are physically connected to each other within 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 utilize advertising, scanning or discovery procedures.

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As seen in [? ]. *Enfatizar*

Remember you can change the reference style. Another dummy citation [? ].

## 2.2 Indoor Technologies

Ha e tal vamos ver o que foi avançado no mundo

bluetooth

### 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 transceivers equipped 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 [? ], 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 to take 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 locat-

ing objects inside buildings. Its objective was to demonstrate that active tags can in fact 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 access 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 existent 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 [?] 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 common 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 doesn'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 consumption. Both these factors allow UWB to achieve high positioning accuracy while the latter enables to address 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, attempts 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 one emitter and a few listeners to obtain a location. Since the locations of the antennas are 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 different 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 [? ], a system capable of tracking active tags equipped with batteries which have a conventional RF transceiver and a UWB transmitter. 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 transceiver 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

[noitemsep] 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 success due to the improvements and size reduction of the sensors, the improvements in computational capacities and the continuous development of image processing algorithms. Optical systems can be described as a moving sensor, for example a smartphone camera, and often times a set of static sensors which detect movement and which utilize AoA techniques to estimate 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 usually required reference 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 originally 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 frequency 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 additional 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 Moghtadaiee et al. [? ] 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. is an emerging wireless technology standard which provides solution for short and medium range communications and its specially 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 interference 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. [?] 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. 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. 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 [?] 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

There are many ways of obtaining the location of an object or person...

### 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

applicable 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 one of the two nodes records the transmission and arrival times, with the conversion 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 transmitter. 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 ignored in medium to long-ranged systems if its value is relatively small when compared to the transmission time. In short-ranged systems 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 conversion of this value to distance is often achieved through estimates of signal path loss due to propagation, although this approach doesn't hold in scenarios where severe multipath effects and shadowing are present.

A technique that is often used with RSSI is the fingerprint method which is the process of computing the location of a user by matching its location-dependent signal characteristics to an existing fingerprint database. This method doesn't require any additional hardware on the mobile device or the beacons as well as no time synchronization. This process is divided into 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 positions are defined on the map. On each of these positions a mobile user captures the signal strengths received from each of the existing 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 existing signal properties, which are then compared with the fingerprint database so that as close as possible a match can be found. Position matching 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 sensibility 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 these lines 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 technique's drawback 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 misleading directions or by the directivity of the measuring aperture. One example which attempted to tackle AoA's drawbacks was ArrayTrack [?] which presented a multipath suppression 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 impractical.

### 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's 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 accuracy 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 combinations have been created in order to tackle this issue. Fischer et al. [?] made use of Ultrasound beacons as landmarks to provide better accuracy and less heading errors. In their work they stated the existence 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

bases:

cricket, It is an ultrasonic positioning system. The Cricket nodes are small ultrasonic devices developed by the MIT Laboratories. A Cricket unit which is a transmitter/ receiver application board is shown in Figure 4. 3D positioning accuracy of 1–2 cm is claimed to be reached with this system in an indoor environment of 10m<sup>3</sup>. The Cricket unit can be programmed either as a beacon or listener. Real-time tracking can also be done with an update-rate of 1 Hz. The system details are given in [22].

Another description of TDoA can be the one presented by the cricket project, presented in section 2.4, which interprets TDoA as the time difference between the arrival of two signals of different speed from the same emitter. Cricket implemented a device which emitted a RF and an Ultrasound signal



simultaneously and computed the distance between both devices through th

radar RADAR is another RF based popular system used for locating and tracking objects or people in indoors [11]. The system records and processes the signal strength information received from base stations. These stations are positioned to provide overlapping coverage of the area of interest. It uses signal propagation modelling to estimate the object location to a great accuracy. Signal strength information collected at multiple receiver locations were triangulated to find the user coordinates. This triangulation was made using emperical approaches and computations of signal strength information. RADAR estimated the user's location within a few meters of his actual location .

#### active badge

Active badges is the first indoor location sensing system developed by ATT Cambridge [3]. See Figure 2. A miniture infrared beacon , worn by every person , emits a unique code identifier every 15 seconds. Each location in a building covered with a network of IR sensors which detect these transmissions. A central server collects this data from fixed IR sensors around the building, gathers into a central data bank, and the location of the badge (hence its wearer) can thus be determined.

Images: [http://paper.ijcsns.org/07\\_book/201005/20100518.pdf](http://paper.ijcsns.org/07_book/201005/20100518.pdf)

#### active bat

ATT Cambridge has developed an ultrasonic tracking technology which provided a better and more accurate indoor positioning then the previous Active Badges. Users and objects are tagged with ultrasonic tags identified as "bats".The system was described in Reference [21]. These bats emitted periodic ultrasonic signals to receivers mounted across the ceiling. This system produced basic position data and additional orientation information. See Figure 3. The problems of using this ultrasonic technique are the requirement of large number of receivers across the ceilings and their placements across the ceiling which needed quite sensitive alignments.

Other projects: DOLPHIN [http://paper.ijcsns.org/07\\_book/201005/20100518.pdf](http://paper.ijcsns.org/07_book/201005/20100518.pdf)

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.

### 2.4.1 RFID



# 3

## **Conclusions and Future Work**



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## **Title of AppendixA**

