GEFILOC: Generic Framework for Indoor Location Systems

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Abstract

Nowadays there is a great demand for positioning systems. While GPS' performance is amazing for obtaining outdoor locations, the same doesn't happen in indoor environments. As such, indoor positioning systems have been studied in order to achieve similar results. In this thesis, one studies the actual state of indoor systems through an analysis on the usable technologies and techniques. A critical analysis is conducted through a modern perspective centered on location services through smartphones. Since there is a great number of different indoor location systems, one found a need to create a framework capable of hosting such systems in the form of a smartphone-centric architecture. This generic architecture attempted to achieve interoperability through the isolation of the main components of indoor systems. As such GEFILOC, a generic framework for indoor location systems, was created. GEFILOC would allow for systems that made use of it, to be capable of operating together on the same device without additional requirements. In order to test the proposed framework, a Bluetooth low energy-based system was implemented. This system allowed the analysis of the energetic costs of the architecture, having shown that the energy consumption associated to network communication had a low impact. This observation was fundamental since this cost was introduced by the isolation of components onto servers, and analysis proves that the proposed trade off comes at an acceptable cost.

Keywords

Bluetooth low energy, Indoor location technologies, location techniques, generic architecture

Resumo

Atualmente existe uma grande procura por sistemas de localização. Apesar do sistema de Global positioning system (GPS) conseguir obter ótimos resultados em ambientes exteriores, o mesmo não acontece quando aplicado a ambientes interiores. Assim sendo, a investigação no campo de sistemas de localização indoor intensificou-se com o objetivo de produzir resultados ao nível do GPS. Esta tese investiga o estado atual dos sistemas de localização indoor, através do estudo das tecnologias e técnicas para calcular localizações existentes. De seguida é realizada uma analise através de uma visão moderna, focalizada em serviços de localização através de smartphones. Devido ao grande número de sistemas existentes, é sugerida uma arquitetura genérica capaz de ser aplicada a sistemas que tencionam usar smartphones como peça central. Esta arquitetura, nomeada GEFILOC, surge com o objetivo de permitir interoperabilidade através do isolamento das componentes principais destes tipos de sistemas. Outro aspeto relevante, é a capacidade de fácil inclusão de novas tecnologias ou algoritmos na estrutura base. De modo a testar o GEFILOC, foi implementado um sistema baseado em Bluetooth de baixa energia (BLE). Este sistema permitiu a análise do seu consumo energético, tendo sido possível concluir que o impacto associado à comunicação internet era baixo. Esta analise era fundamental, visto que este seria o único custo introduzido pela utilização do GEFILOC. Este custo está associado ao isolamento das diversas componentes em servidores e assim foi possível provar que o compromisso é atingido sem causar um impacto relevante.

Palavras Chave

Bluetooth de baixa energia, tecnologias para localização interior, técnicas de localização, arquitetura genérica

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Abbreviations

AoA Angle of Arrival

BLE Bluetooth Low Energy

CoO Cell of Origin

CSI Channel State Information

DR Dead Reckoning

FM Frequency Modulation

GPS Global Positioning System

IoT Internet of Things

IR Infrared

LAN Local Area Network

LOS Line-of-Sight

PHY Physical

RF Radio Frequency

RFID Radio Frequency Identification

RSSI Received Signal Strength Indicator

TDoA Time Difference of Arrival

ToA Time of Arrival

US Ultrasound

UWB Ultra-Wideband

WLAN Wireless Local Area Network

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 Global Positioning System (GPS) [6], a system whose development began 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 widely available to anyone, allowing for outdoor location to become something of our everyday life in the form of navigation systems.

With the GPS taking the crown in the outdoor location system due to its incomparable success, the research target changed to indoor location. When transitioning from outdoor to indoor, new constraints are presented onto the process such as the attenuation and reflection of electromagnetic waves upon collision with building walls and obstacles [7]. Since GPS is an outdoor position systems based on a network of satellites, its performance is heavily impacted by these constraints. This created a need for finding reliable indoor systems capable of performing under said circumstances.

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; non-existence of line-of-sight; influence of obstacles such as walls, furniture and movable objects such as doors and human beings [8].When using RF labels, all of the previously mentioned factors affect the way electromagnetic waves propagate in an indoor environment leading to problems related to severe multipath and reflection on existent surfaces [9].

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 characteristics are a much smaller range and site-wise deployment, effectively reducing the number of obstacles between the technology device and the user. These smaller scale technologies are meant to be deployed inside buildings and in much greater number due to their reduced cost. Over the course of the last ten years, the technologies that were labeled as the ones capable of providing better indoor location systems have been ever-changing as with time the technologies themselves have evolved as well.

One of the biggest factors for it has been the parallel 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). Smartphones have introduced new possibilities to the world of indoor location using high sensitivity antennas for RFID , Wireless Local Area Network (LAN) and Bluetooth among others, allowing the deployment of hybrid systems which make use of more than one of the technologies mentioned above[7, 9, 10].

1.1 Motivation

With the recent technological advancements, smartphones are now capable of carrying a wide variety of sensors. This opportunity, in addition to its wide utilisation, made smartphones a perfect candidate for indoor location systems. Therefore, systems that make use of technologies that are compatible with smartphones, are capable of taking advantage of them, removing the need of having system-specific devices.

Currently the attention is focused on the improvement and creation of new means to achieve better positioning results, as it is possible to notice from the vast number of existing methods and algorithms available to infer someone's location. Although this part is of great importance, as the success of a location system in the present day is highly dependent on its accuracy levels, another relevant concern for any system is their energetic consumption.

With smartphones being heavily used by any modern system, it is fundamental to comprehend that they are personal devices with a limited amount of resources. The most relevant resource is the battery, a constraint that can't be entirely taken by the system.

Another important factor is that an indoor system needs to be scalable, with respect to the number of users in the same indoor building or in terms of being capable of working with different deployments/buildings. Systems created with the purpose of being used in different environments need to provide an architecture capable of working seamlessly when moving between buildings. As such it is required that the smartphone (mobile agent) is capable of obtaining its own location wherever the system is deployed.

Since we live in an era dominated by smartphones, their evolution has allowed for developing systems which rely on its sensors and processing capacities to present a solution which isn't dependant on specific hardware. The first condition that is imposed onto the systems is the compatibility with smartphones, i.e. the required sensors needs to exist on the generic hardware of smartphones. Once this barrier is surpassed, these generic systems are immediately faced with three fundamental decisions which will define the architecture of the system and which can be seen on Figure 1.1.

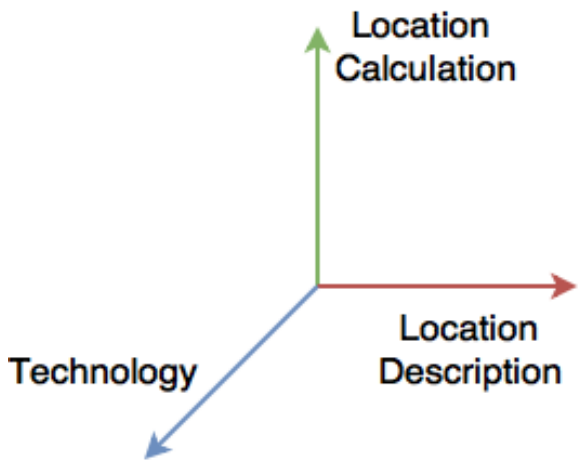

Figure 1.1: Three fundamental choices in Indoor systems

The first decision, Technology, defines the technology which is to be used in conjunction with the smartphone and consequently the way that location data is to be collected. There is a wide range of possibilities for this choice, be it BLE beacons, Wi-Fi Access points, LED lamps or just the microphone for sound collection, and each has an impact on the way that the system functions and on its performance.

The second question is the location algorithm, which fundamentally depends on the target requirements of the system, if it's required to provide accurate location of a user or if a more descriptive location, such as indicating the room in which the user is located, is enough. There is already a great number of different usable algorithms for each indoor capable technology. Therefore, the choice depends on the way that distance calculation is obtained, be it through time or signal strength, and obviously the technology.

The third and last question is about which way the location will be described. When dealing with outdoor location systems, the provided location is always characterised by four values: latitude, longitude, altitude and datum. In indoor systems, the surrounding environment can be of many shapes and as such different ways of representing location are necessary. If one thinks about providing indoor location in an office, the precise location isn't as relevant as just knowing the general location, i.e. a building specific description of the location in the form of building, floor and room. On other environments such as supermarkets or even in the previous example, where the objective is to provide a more precise location description, a cartesian coordinate system (x,y) is required.

1.2 Objectives

The objective of this thesis is to present and implement a generic architectural framework whose intent is to provide an indoor location and satisfy the indoor requirements presented in 1.1. A system implemented on this framework should be capable of keeping its energetic consumption to a minimum and allowing itself to be scalable, deployed in multiple sites and allowing multiple location representations and algorithms.

The previously mentioned generic architecture framework can be visualised in Figure 1.2. This architecture makes use of the technological developments on mobile phones to use them as the central point of communication of the architecture. This compromise brings onto the table a trade-off where scalability and interoperability are sought in exchange for added communication complexity. On this architecture the beacons are responsible for providing the smartphone information about its surroundings, information that is later on passed onto the location server. This server is responsible for computing the user's location and send it back to him. Once the smartphone is aware of its position, it can request the map server and present the result of the whole process visually to the user.

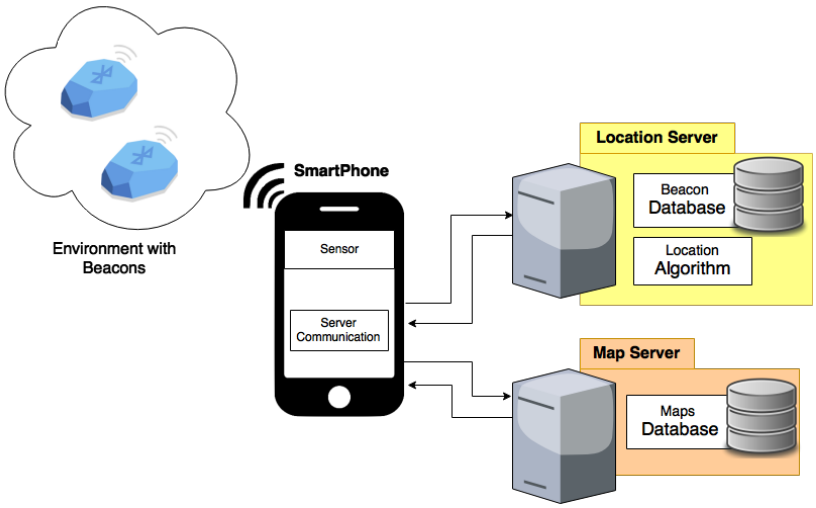

Figure 1.2: Generic Architecture Framework

In order to implement and test the architecture, it was necessary to select the various technologies to use. The chosen technology for the beacons was the Bluetooth low energy, a recent technology that is trying to improve itself in order to be usable on Internet of Things (IoT) and it was capable of providing room-based accuracy without a complex algorithm. The beacon component of the architecture was implemented by making use of BLE enabled devices. Each of the devices is uniquely identified and knows the identity of its location server. Whenever a mobile device is nearby one of the beacons, it's capable of establishing a connection with the beacon. This allows it to confirm that the beacon belongs to the indoor location system and to access its data, i.e. the address of the beacon's associated location server.

Once the mobile user has all the data from surrounding devices, i.e. he has data associated to the signals collected from each beacon and the address of the server, he can forward it to the location server. The location server has a database with all of its associated devices, that is used to validate the beacon data. Upon confirming that the devices belong to it, it can calculate the user's location through its location algorithm.

Upon receiving the user's location, the smartphone is just missing the visual representation of the location. To do so, it sends its location to the map server. The map server in the generic architecture framework represents a server which has a database of all the maps for a certain location server. For this implementation the used map server was google maps since its indoor maps feature was available in the testing place. As such, the location of the mobile user is requested to google maps through its API and presented to the user on its smartphone's screen.

The study of the system's energetic costs was created with two questions in mind: What's the impact of the number of nearby beacons? and What are the costs associated to the network communication? The answer to both questions would demonstrate how the overall system performs. Since all test results contain the base costs linked to the smartphone, it was vital to start-off by attaining those. Therefore four test were conducted: One with the smartphone inactive (sensors deactivated), two for the Wi-Fi (with and without service) and the last with all sensors active. By making use of

these results it would be possible to better comprehend the remaining.

For the first question, tests were carried out where two factors were tuned, the number of nearby beacons and the location query's cycle period. From the result's value it was possible to observe the system's high costs. These values are explained by the unoptimised state of the system, evidenced by the fact that the same one/two devices are repeatedly queried for their data in each cycle. In a more optimised solution, the beacon data would be temporarily stored on the smartphone, reducing the costs associated to the BLE communication.

Meanwhile for the second question, tests were conducted in two different scenarios: One where the system's complete cycle was performed and the other where the cycle was interrupted once the BLE communication was finished. Both scenarios were tested with the same amount of nearby beacons and the same cycle period. Through the comparison of both, it was possible to evaluate the impact of the system's network communication, which was fundamental since it consolidated the accepted trade-off for scalability and interoperability. Although the network communication costs aren't negligible, one believes that they are acceptable when taking into consideration the advantages of the proposed architecture.

1.3 Thesis Outline

Chapter 2 of this thesis examines the state of the art of indoor location systems. It commences with an overview of the current technologies and algorithms for location calculation, passing through examples of existing systems and finalising with a critical overview of all the mentioned subjects. Chapter 3 presents the architecture of the projected generic indoor system by analysing each component according to its responsibilities, while Chapter 4 demonstrates the implemented BLE solution based on the previously presented generic architecture. To finalise, Chapter 5 shows the experimental tests that were conducted and the associated results.

2

Indoor positioning

Contents

This chapter gives an overview of the state of the art of indoor positioning solutions.Section 2.1 starts by introducing the most common techniques used for location calculation, while Section 2.2 overviews the existing indoor compatible technologies. Section 2.3 analyses the systems that had the most relevance in the field alongside existing Bluetooth Low Energy (BLE)-related systems. In Section 2.4 an overview of the existing formats for describing locations is given and finally, Section 2.5 presents a critical overview of all the technologies and system previously presented in the chapter.

2.1 Location calculation techniques

This section's focus is on the available means of obtaining distance measurements from a mobile target to a beacon. Figure 2.1 displays a representation of the beacon-smartphone interaction. Whenever a location calculation is requested, the collection of data from nearby reference points is mandatory. In indoor location systems, these reference points are provided by beacons deployed in the location environment. The type of information collected, that is afterwards translated into distance, can be of several different types. The following section will target the different means of obtaining distances, as well as how to calculate a location from them.

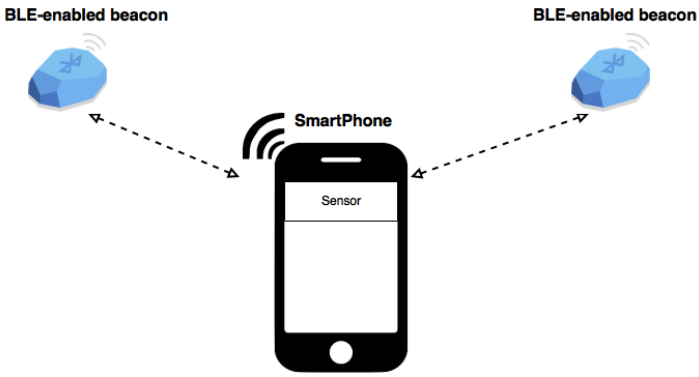

Figure 2.1: Beacon and Smartphone interaction

2.1.1 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[8]. 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 order to apply room-based accuracy, the minimum requirement would be to place a beacon in each existent room. This method can be applied with a better accuracy in mind and doing so, it depends only on the deployed beacon density. This technique is often implemented in systems running Infrared (IR) , Radio Frequency Identification (RFID) and Bluetooth.

2.1.2 Triangulation

The Triangulation techniques make 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. The metrics used for location calculation with either of the types, will now be presented.

2.1.2.A Time of Arrival (ToA)

Time of Arrival (ToA)-based systems rely on accurate clock synchronisation and signal message sent from a mobile target to several receiving beacons [11]. The distance that is to be used in the calculation of the target's position is proportional to the propagation time. The message sent from the mobile target is timestamped with its departure time allowing for the receiving beacons to obtain 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 synchronised 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 other hand, the disadvantages of using this technique is the synchronisation requirements and the additional information that needs to be contained in the sent messages, i.e. timestamps.

2.1.2.B Time Difference of Arrival (TDoA)

Time Difference of Arrival (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[12]. This technique doesn't require clock synchronisation 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 obtained from a transmission with unknown starting time that is received in multiple synchronised receivers which produces multiple TDoA measurements. 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 measurements in order to obtain the location on a two dimensional plane.

2.1.2.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[13]. This solution solves some of the synchronisation issues presented by ToA since 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 the receiving node which 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 system this situation can't be applied and therefore this technique isn't suited to be applied.

2.1.2.D Received Signal Strength Indicator (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 synchronisation. 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 positions are defined on the map. On each of this positions a mobile user captures the signal strengths received from each of the existent beacons. An example of this method's data collection setup can be seen on Figure 2.2. 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 existent signal properties, which are then compared with the fingerprint database so that a close as possible 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 to be in accordance with 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.

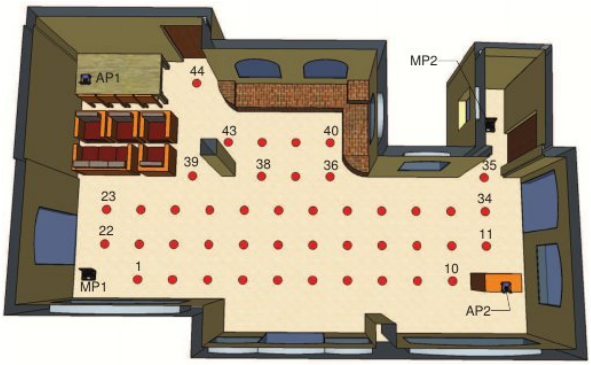

Figure 2.2: Fingerprint example with data collection positions (Ref [1])

2.1.2.E Angle of Arrival (AoA)

The Angle of Arrival (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 synchronisation[14]. This technique has two drawbacks: Increased implementation cost, since antennas capable of measuring angles are costly; Rapid accuracy degradation, i.e. the accuracy is heavily affected by the distance between user and beacon. This technique is capable of sub-meter accuracy although these types of systems are often limited by shadowing, multi-path reflections arriving from misleading directions or by the directivity of the measuring aperture. One example which attempted to tackle AoA's drawbacks was ArrayTrack [15] 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 utilising custom made access points with 16 antennas. Although successful, the hardware complexity remained an issue making this system impractical.

2.1.3 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, once 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 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 doesn't function in indoor environments, leading to the implementation of many different combinations, in an attempt to tackle this issue. Fischer et al. [16] 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 advanced through the building.

2.2 Indoor location support 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. Therefore, it's important to look at each of the possible technologies individually and assess its benefits and drawbacks as well as their performance[10].

In this chapter, many existent indoor positioning technologies are analysed. The most pertinent ones, Radio Frequency Identification (RFID), Commodity wireless technologies, Infrared, Ultra-wide band and Bluetooth low energy, are explained in a more detailed manner, while the less utilised

technologies are described in Subsection 2.2.6. 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 existent system that makes use of the specific technology being described.

The information provided on each technology was gathered from a set of surveys on indoor location [7, 9, 10], as well as the information present on the mentioned systems associated to each.

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 counterparts [9]. 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 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[7]. The non required LOS characteristics comes from its radio frequency nature. Radio frequency signals are composed of electromagnetic waves and as such are capable of passing through obstacles at the cost of signal strength. 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 [17], 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 utilise the received RSSI as a metric for obtaining inter-tag distance.

Another important project using RFID is LANDMARC[18] which utilises active tags to produce a location sensing system for locating 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 Received Signal Strength Indicator (RSSI)

readings(a value used to evaluate the strength of a radio signal), as such the used readers scan through eight discrete power levels in order to estimate the RSSI.

2.2.2 Commodity wireless technologies

Commodity wireless technologies 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 Wireless Local Area Network (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 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 analysed in Section 2.1, with multiple projects for each one of the existing 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 Physical (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 [2] 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 calculation 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. The performance comparison showing the differences in temporal stability between RSSI and CSI can be seen on Figure 2.3.

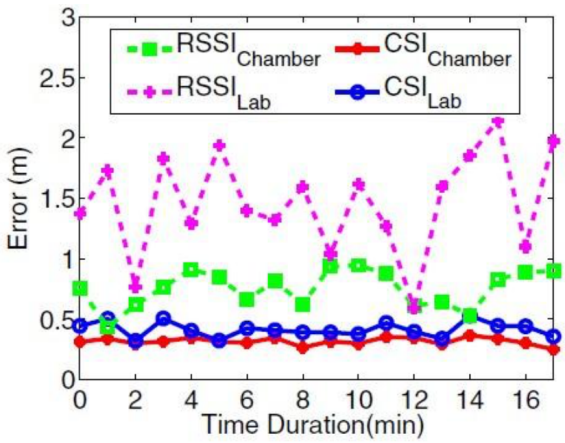

Figure 2.3: Comparison of temporal stability (Ref [2])

2.2.3 Bluetooth low energy

Bluetooth low energy was introduced as an improvement to the already existent Bluetooth, aimed at Internet of Things (IoT). Its most relevant improvements from the classic Bluetooth were the reduced power consumption, lower complexity and lower power consumption. BLE operates in the same frequency range as the classic Bluetooth, allowing them to make use of the same antenna, and as Wi-Fi. This technology is known for its short-range, overall low power consumption and low-cost transceiver chips. BLE's initial target was localised advertising and "near-me" applications, due to its proximity sensing capacity. Nevertheless, its viability as an indoor location technology has been studied, showing that it can be used alongside fingerprinting or with proximity detection. Both techniques make use of RSSI, which in the case of BLE is not a reliable measure. This condition is caused by the sharing of the same frequency band as Wi-Fi, leading to possible signal interference that causes signal fluctuation. In Section 2.3.5, examples of BLE systems are provided.

2.2.4 Infrared

IR systems are mostly used for tracking 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. One of the most relevant systems based on IR is the Active Badge system which is described in Section 2.3. 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 employed by the active badge system and it involves placing fixed IR beacons on known positions. The density of deployment of beacons has a direct impact on the system's accuracy. If a system was required to achieve room-based accuracy, i.e. being able to tell in which room a user is located, a beacon per room would be sufficient.

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 use 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.

2.2.5 Ultra-Wideband

Ultra-Wideband (UWB) is a radio technology aimed at short-range high-bandwidth communication. Its best characteristics are the 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 on 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 ToA or 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 employs 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 synchronisation. One commercial example of this technology is Ubisense [3], 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 AoA techniques to determine the tags location, achieving an accuracy of 15 cm in a typical open environment. The system's setup can be visualised on Figure 2.4.

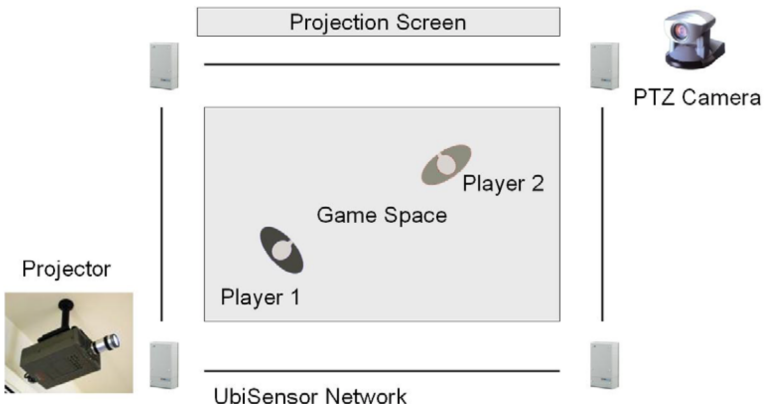

Figure 2.4: Ubisense's system setup (Ref [3])

2.2.6 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 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 employ 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 locating. One crucial part when using 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. [19] 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 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 employ RSSI for distance calculation and one of its most relevant disadvantage is 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. [20] which attempted to locate a mobile device in an indoor environment. Their system consisted of two phases:

- In the first phase, calibration, every ZigBee node communicated with the remaining. In

this way, it was possible to work out the relationship between measured RSSI values and geometric distances, allowing to map the environment.

- In the second phase, location, the mobile device communicated with the existing ZigBee nodes. This information, together with the one from the previous phase, was used to calculate the device's location. This system was capable of achieving an accuracy with an average error of 3 meters.

Ultrasonic Systems are employed in indoor positioning by making use of ToA to locate targets[21]. These kind of system make use of ultrasonic transceiver 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 2.3.

2.2.7 Hybrid systems

Hybrid positioning systems combine several different positioning technologies to determine the location of a user or object. Hybrid systems make use of multiple 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 [22] 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 Indoor location systems

2.3.1 Active Badge

In 1992 the Active Badge system [23] was presented as an infrared solution capable of providing room-based position tracking. The system has been designed to make use of "active badge" beacons, which can be visualised in Figure 2.5 in the form of ID cards, a tag equipped with an IR LED that emitted a unique code for approximately a tenth of a second every 15 seconds.

Figure 2.5: Active badge's tags (Ref [4])

The decision to use IR was caused by the small and cheap characteristics of the emitters and detectors[24]. By being capable of operating within a 6 meter range, IR signals aren't capable of traveling through walls. The signal frequency has two major effects on the system: Firstly it impacts the tag's energy consumption, where a small frequency allows for long periods of work on a single battery; Secondly it impacts on user detection accuracy. 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, with a 15 second granularity.

The position of a user is obtained through the implementation of a network of sensors which act as receivers, continuously listening to badge transmissions. Upon collecting a transmission, the obtained information is sent to the master station. The master station is responsible for polling all the sensors on the network, storing sighted badges into a database where its associated time, position and ID are stored, 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 [25].

2.3.2 Active Bat

In 2001 the Active bat system [26]was introduced. It is 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[27]. The receiver network and a deployed bat can be seen on Figure 2.6;

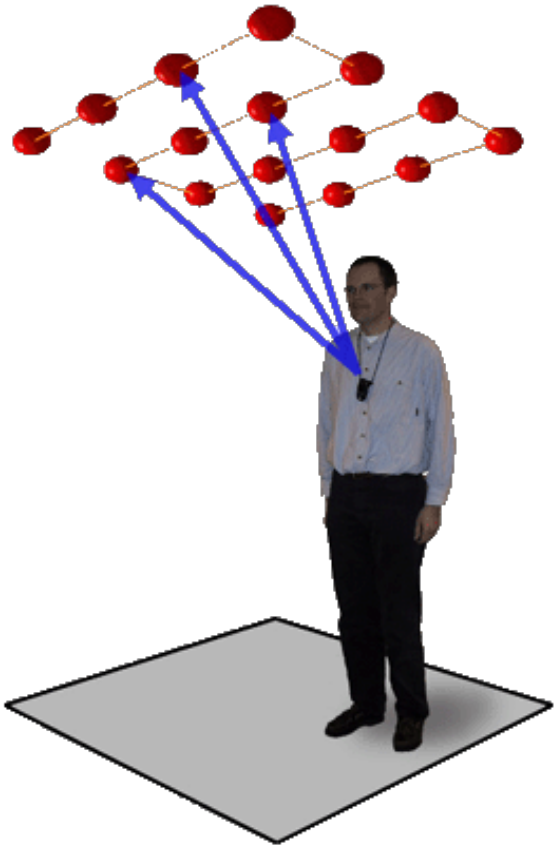

Figure 2.6: Active bat network and device (Ref [5])

A bat, which can be seen in Figure 2.6 being carried by the user, consisted of a radio transceiver, controlling logic and a ultrasonic transducer, 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 ultrasound. 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 three dimensional space, for as long as 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 divided into time-slots, each being capable of locating one and only one bat.

The latest version of the bat included a sensitive motion detector that allowed it to tell the base stations whether 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 starts moving. This implementation allowed for extra power savings while freeing up location-update opportunities for other bats [28].

2.3.3 Radar

In 2001 the RADAR system was introduced as the first Wi-Fi signal-strength based indoor positioning system [29]. The system is Radio Frequency-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 2.1.2.D, to triangulate 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 utilising the methodology already described for the fingerprint method.

Radar's architecture involved a mobile device, base stations and a central station. The mobile device is solely responsible for sending signals to the base stations. During the process of developing the system, the device was a Windows-based mobile host capable of broadcasting packets. The base stations act as gateways, in a way that it listens for the user's signals and consequently forwards its information to the central station. The central station is in charge of storing the whole fingerprint information in the offline phase and calculating the user's location during the online phase.

Data processing involved computing the mean, the standard deviation and the 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 model 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 predicted to be the one that best matches the observed data. In addition to this basic strategy, two others approaches were analysed: empirical and signal propagation methods.

For the first method many variations on the data were studied such as: The number of best matching values used (K-nearest neighbours (KNN)). The results showed that the benefits of averaging between multiple neighbours isn't very relevant, even for small values of k. In general the empirical method was capable of estimating the user's location with high accuracy, obtaining a median error distance between 2 and 3 meters. 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 how well the used model is capable of correctly describing the signal. 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. Although it isn't as accurate, it can be considerate as a solution when analysing its benefits.

2.3.4 Cricket

The Cricket system[30] was developed by the Massachusetts Institute of Technology (MIT) in 2005 and managed to tackle some of the problems existent 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 Radio Frequency (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 utilises the RF signal's beacon information alongside the obtained 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 each other. With this information it is then possible to obtain the beacon's coordinates.

Cricket's architecture is completely decentralized, since it doesn't require a central node. The used nodes are responsible for communicating with the beacons and calculating their own location, while the beacons are responsible for finding their positions and transmitting their information to the listeners.

The utilised method for computing distances doesn't require listeners to actively transmit messages which permits cricket to perform well independently of the number of users. This active-beacon passive-listener architecture makes it so that the position of the user isn't tracked by the system thus solving the user privacy issues that were present in the remaining projects.

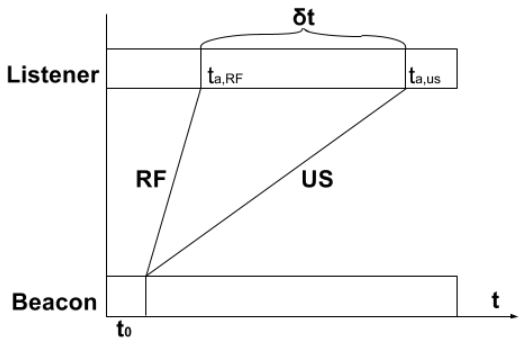

Figure 2.7: Cricket's TDoA representation

Distance measurement is computed through TDoA using both RF and US signals and it can be visualised in Figure 2.7. Since the velocity of the RF signal is much higher than that of the US signal, the US signal lags behind when compared to the other. As such, whenever a listener receives a RF signal, it measures the time it takes until the US signal arrives, denominated δT. With knowledge of the speeds of sound and light, the distance between beacon and listener can be obtained from:

$$\delta t = \frac{d}{v_{US}} - \frac{d}{v_{RF}} \tag{2.1}$$

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 80 degree cone from a given beacon, position accuracy of 10-12 cm and an orientation accuracy of 3º - 5º.

2.3.5 BLE systems

When looking at what's possible to achieve using the BLE technology there is the example of Apple's creation iBeacon [31] which was presented in 2013 with the purpose of implementing proximity sensing systems. The devices are implemented as broadcasters, making it so that its objective is to send information to nearby compatible receivers. 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 practical 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 using this technology was presented by Jingjing Yang et al [32], where these devices were used to indicate a patient of his whereabouts through the proximity sensing properties and this information was later transferred over to a server

in order to give clients a variety of different services, from patient counting, to nearby department's information and offer indoor guidance to the nearest available bed.

When using BLE for indoor location, the metric used to calculate distances is the RSSI. This metric within the context of Bluetooth brings to the 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 with the inverse of the square of the distance to the beacon. As such when developing solutions for indoor location that require systems with high accuracy capable of tracking moving objects, the usage of RSSI can't be utilised without further work. Faragher et al [33] 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: low scalability; requires higher density in order to increase accuracy; due to their low range, increasing coverage leads to increased costs.

Zonith [34] 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 respond within a time interval (Lone worker protection) or providing a quick a precise location of any worker that has requested for help. This system's installation requires planning of the best locations to place the beacons and number of beacons required, in order to be able to provide enough coverage and assure the system's required quality.

2.4 Location description formats

In order to better understand the existent various ways of describing locations it's better to look at existing solutions and the methods they employ. The most common method of describing location is through latitude and longitude, much like the Global Positioning System (GPS) does, with the biggest example that makes use of it being Google maps. Google maps, through its indoor maps platforms [35] allows integration of indoor maps onto their google maps. Since Google Maps uses this type of location description, the indoor component of it follows the same routes. An indoor map on the platform is inserted into its original geographical location and in the case of having multiple floors, it is possible to navigate through them. This indoor component is of relatively small complexity, likely due to google's reduced investment onto indoor location system, leading to a small amount of indoor specific characteristics.

Another method is to consider the indoor map as the location reference and utilise a cartesian coordinate system, x and y, to represent a location. Meridian, an indoor location system developed by HP [36], presents functionalities such as route making and push notifications through its beacons. The indoor map insertion is accomplished through Meridian's online platform. As such there isn't the outdoor component that google indoor maps has but it allows for utilising a (x,y) system relative to the building map. While no complex building description is allowed, it is still possible to indicate the

position of specific elements such as restrooms or stores.

Although Meridian already provides some extra level of detail in comparison with google indoor maps, there is another example that should be mentioned called OpenStreetMap. Although it started much like google, providing global data, due to its openness, many indoor projects surfaced such as OpenLevelUP [37]. This project makes use of OpenStreetMaps' current indoor tagging scheme [38], which is intended to describe in the most complete and simple way a building. This makes available the number of floors, the type of elements (room, wall, corridor, etc) and its connectors, like doors and escalators or elevators, allowing to understand clearly the map that is being analysed.

2.5 Critical evaluation

In this section we want to review all the technologies that have been presented in this chapter but this time comment and evaluate them with a modern day's vision. It is of relevance to understand which technologies present concepts that can still be easily usable in the present and whether or not they can be adapted to function with state-of-art smartphones. There are four core concepts that will be analysed: The level of difficulty in deploying the system; the accessibility of the system towards users, mainly focused on the compatibility with modern smartphones; the scalability of the systems; and finally the privacy of the systems.

2.5.1 Deployment of beacons and scalability

When deploying a system, there are factors that determine how troublesome it is. One factor is the cost of the beacons. Costly beacons can be an obstacle when the number of beacons required to be deployed increases. This number depends on the range and the precision demanded. A system's scalability depends on the possibility of increasing the infrastructure and covered area, as well as being capable of handling an increase in the number of users. Due to the high number of various technologies and correspondent systems, each one will be analysed separately.

Radio Frequency Identification (RFID) The analysis of this technology can be achieved through one of its systems. A recent one was presented by Han Zou et al. [39] which makes use of RFID tags and sensors, a RFID reader and a location server. The general procedure for calculating a location is:

- The tags emit their ID, which is caught by the sensors;
- The sensors make use of its external power supply to allow the creation of a continuous wireless connection with the reader. It's through this connection that any captured tag information is sent;
- the reader receives the data and forwards it to the server where the location is obtained.

This system introduces one of the issues of RFID which is the high cost of readers. In this type of architecture, where the objective is for tracking, the deployment of beacons is equivalent to deploying sensors and readers on the areas that are to be covered. As such, increasing the

covered area ends up being a costly operation. Nevertheless, since tags are cheap and a user is required to carry just one, user scalability isn't an issue.

When envisioning a RFID system centralised on the users, the roles associated to the tags and sensors plus readers are exchanged. As such, in this scenario, the user scalability would be costly. This occurs since each user would be required to carry a reader. With the reference points being provided by RFID tags, the covered area expansion becomes a cheap operation.

Commodity wireless technologies In order to study these technologies, the radar system will be used.

Radar's architecture defines the mobile user as the broadcaster for the whole of its process, be it offline and online phases of the fingerprint method as described in Section2.3. Radar's deployment is dependant on a grid of access points and devices for each user. Nowadays both dependencies are often unnecessary since all mobile devices can use Wi-Fi and many indoor environments are already equipped with Wi-Fi access. Due to its wide availability, these system's deployment costs low when compared to other technologies. Despite the architecture, P. Bahl et al[40] comment on its consequences, imagining that in a real situation, since the number of mobile users is vastly bigger than that of base stations, the inversion of the roles would be beneficial in order to decrease the complexity and the workload. Passing the broadcast role to the base stations while having the mobile users function as listeners, would make it so that for a certain floor the complexity would be constant, i.e. equal to the number of stations, instead of being unstable like the number of mobile users. This changes would increase the scalability in terms of users for this system.

Wi-Fi systems often calculate a users location through either trilateration or fingerprint. In the case of fingerprint, the one used by Radar, the complications associated to the technique can reduce scalability. When compared to other techniques, this one has additional maintenance concerns, since it's not about changing a beacon or its location but about updating the areas fingerprint. When an update is required, the whole process must be redone, leading to high costs that are associated to the coverage of the system.

Infrared (IR) An example of a recent system based on this technology is the Epsilon project[41], which makes use of Light-emitting Diode (LED) and light sensors.

Epsilon makes use of LEDs and their capacity to both illuminate and communicate. Through the LED's ability to instantaneously change between on and off state, it is possible to carry digital data in the visible light carrier through Pulse Width Modulation (PWM). In this system each of the used LEDs was self-contained, i.e. it knew its own location, which was inserted into the data transmitted to the mobile user. The mobile user would capture the LED information through its light sensor, and consequently decode the received data from each of the available sources in order to make use of trilateration to obtain its position.

Epsilon presents a solution which is easy to use in today's world due to the availability of LED

lighting in indoor environments. Much like the systems that profit from Wi-Fi, this one is capable of profiting from the existing infrastructure for its deployment. The associated cost would then be associated to the adaptation of infrastructure to the one required by the system. For the mobile users, with the required sensors being available in most smartphones, the deployment isn't a problem.

Epsilon's architecture was created with the intention of having a "plug-and-play" kind of system, made possible through the self-contained LEDs and location calculation made on the smartphone. These characteristics have an impact on the system's scalability. When presenting the system, the authors suggest a way to tackle this issue. Through the use of a back-end service for mapping the IDs of each LED to their location and by transferring the location calculation algorithm to it. This addition to the current architecture would boost the system's scalability since whenever an update or modification to the system's algorithm is required, interaction with every single device is required.

Ultra-Wideband (UWB) This technology isn't practical for personal indoor location in today's world. The main reason is dependency on system specific hardware which invalidates the possibility of having a wide scale indoor location systems.

When analysing recent UWB systems, the most common ones are tracking only systems. These systems are found useful in construction environments, where tracking crane's position is of relevance [42]. This position tracking is accomplished by setting up a network of UWB sensors on the construction site and placing UWB tags on the crane or parts of it, if the whole position and pose of the vehicle are of relevance, that is to be tracked. While the addition of new target implies only the deployment of new tags, the sensors high cost are the limiting factor on the technology's deployability and scalability.

Despite the difficulty, Decawave [43] attempted to introduce an indoor location solution. Decawave presents a UWB transceiver in the form of a hardware module. The deployed beacons would be the traditional LED lights, with the addition of an UWB transceiver, allowing them to communicate with the mobile user's device. Since this device would still be system-specific, the system's deployability and scalability are still reduced.

Optical As described in Section 2.2.6, optical systems are systems which are dependent on cameras, as means to obtain input for indoor location. One example is the already analysed system, Epsilon, where the camera is used as a mean to capture IR signals from LEDs.

Other variants of camera-based systems make use of depth cameras with the intention to build dense 3D maps of indoor environments [44], which can be useful in robot navigation. Due to their high cost and incompatibility with modern day smartphone, these variants can't be used for large scale indoor location systems.

FM FM as a technology for indoor location can be used, but often it's discarded in favor of other possibilities. One example of a FM system was presented by Sungro Yoon et al. [45]. The

proposed system was capable of providing indoor location through a fingerprint method and the signals from commercial FM radio stations. The utilisation of a publicly available signal ,i.e. existent commercial radio stations, removes the requirement for extra infrastructure. Since user's device compatibility isn't an issue, the deployment of this technology is non-existent. Nevertheless, since it makes use of the fingerprint technique, additional costs are taken into consideration, much like the case of Radar. Other than the limitation from fingerprinting, there are no more scalability concerns, since the required infrastructure is constant.

US Although one could analyse the technology through the cricket or the active bat system, a more recent example will be used. Viacheslav F. et al [46] presented a location system based on the capability of producing US signals using a smartphone's microphone. The presented system made use of a smartphone as the central piece, which interacted with the system through a mobile application. Although it was a promising approach on indoor location, it falls under the limitations of the technology. Since US signals require an existing LOS between sensor and smartphone, the infrastructural requirements are higher than many of the remaining technologies. In order to deploy the system, a grid of microphones needs to be set up in each room, which due to the low range, requires a great number of them. This condition greatly affects the scalability of the system, as well as the fact that an increase in the number of users, may cause issues related to line of sight.

2.5.2 Availability on users devices

Creating a system that makes use of a publicly available device is only possible through smartphones. As such, this concept is entirely dependant on the smartphone's capability to interact with a technology. This capability is determined by the available sensors on the device. Taking the iPhone 6 as an example, one can list its sensors[47]: Wi-Fi antenna, making commodity wireless technologies systems possible; 4.2 Bluetooth antenna, allows Bluetooth and its most recent version, Bluetooth low energy, to make use of smartphones; FM antenna, for FM radio systems; Camera and light sensor, allow for optical, as well as infrared systems; microphone, for sound-based systems; and barometer, three-axis gyroscope and accelerometer, that can be used in systems that employ dead reckoning or that used them as support sensors in hybrid systems. Apple systems have one extra possibility, in the shape of iBeacon communication capacity, a technology used by the system presented in Section 2.3.

From the list of technologies that are available for indoor location systems, the ones that aren't made available to users through smartphones are: RFID, since these type of indoor systems make use of RFID readers, which aren't available on smartphones; Ultra-wide band (UWB), which makes use of antennas that are not present in current devices. ZigBee systems aren't compatible with smartphones for the same reason as UWB, missing antenna.

2.5.3 Security

When users are presented with a location system, one of their concerns is their privacy. Privacy is described as whether or not someone other than the user, at the time of a request, has access to the obtained location. In order to analyse the different levels of privacy, one can look at the architectures of the cricket system and the active bat system, both already presented in Section 2.3. Active bat's system is tightly controlled and centralised, i.e. the position calculation and visualisation happen on the central station of the system. Although this system was capable of tracking users, instead of providing them with their location, it introduced concerns such as the user's willingness of not being tracking and the location's data security. While the first concern's solution was to disable the tag, the other required the improvement of the control access to the central station.

On the other side of the spectrum, cricket presented a decentralised architecture. One on hand, the beacons were capable of finding their location through the others present in its vicinity, and on the other hand, the system's device was capable of providing the user with its location, without the need of an external entity. Since the device is capable of obtaining its own position, there is no need to pass the collected information to someone else, guaranteeing the user's privacy.

In order to obtain a more recent view on privacy, one can review the Epsilon system, which was presented in Subsection 2.5.1. Although its system is capable of working as-is, where the location is obtained on the smartphone and the privacy of the user is achieved, in a bigger scale deployment it would face scalability issues. When presenting the system, the authors suggested a way to tackle this issue. Through the use of a back-end service for mapping the IDs of each LED to their location and by transferring the location calculation algorithm to it. This modification would create the requirement of a network connection, while also removing the user's privacy.

From this example, and many other systems/services in our lives, scalability is gained in exchange for user privacy, an exchange often accepted.

3

Architecture

Contents

This chapter describes the proposed generic architecture, GEFILOC, for indoor location systems. Section 3.1 describes the requirements that are presented to any system that intends to implement the generic architecture, while Section 3.2, provides a complete description of the presented architecture's components as well as their requirements.

3.1 System Requirements

Before defining a generic system it is fundamental to define the requirements that those need to implement. In a system like GEFILOC, these requirements can be of many different types: energetic, functional or scalability requirements. In the end of this document an evaluation of these requirements will be presented.

Functional requirements The whole architecture revolves around having a smartphone as the central point for communication. As such, a system like GEFILOC is required to be **capable of calculating a position**. Such a requirement is dependent on other functionalities. Calculating a position is only achievable if the system is **capable of gathering information from beacons**, which is also dependent on the system's capability of **communicating with its chosen technology's beacons**. The other required functionality is that the system needs to be able to display the user's calculated position on a map.

Energetic Requirements One of the concerns when making use of the smartphone as the central node of communication is the fact that the whole system is reliant on the energetic availability of the smartphone. As such it is crucial to make sure that the energetic impact of the system, when it is functioning, is the smallest possible.

The energetic impact per single operation associated to the system depends on multiple factors such as:

- Energetic capacity of the smartphone, whose values have been increasing over the years in order to support the higher energetic requirements.
- Cost of the communication between beacon and smartphone, which depends on the used technology.
- Cost of the communication between smartphone and servers, which depends on the size of the messages and the frequency at which they are sent.
- Cost of the technology's scanning procedure.
- Cost of displaying the maps on the smartphone application.
- the overall cost of the application utilisation.

When analysing the costs of each of the previously mentioned factors the costs associated to scanning and communication between beacon and smartphone are the most pertinent ones. These cost are dependent on the technology's specific sensor. The remaining communication

cost are relatively constant and are independent of the chosen technology. These costs depend mostly on the size of the transmitted messages, which for the ones between smartphone and location server depends on the number of surrounding beacons and for the ones between smartphone and maps server depends on the size of the maps on the maps server.

The overall cost of the system is dependent on the frequency of the operation. The system's energetic impact can be reduced through the optimisation of the system's update frequency. This optimisation should target the user's movement, since while the user is stationary, no updates on its position are required. Update frequency also has an impact on the precision of the calculated position. This situation introduces a tradeoff on this frequency between consumption and accuracy. While a high update frequency allows the system to provide to the user precise information about its location, it also increases the system's overall consumption.

Interoperability requirements The concept behind the proposal of a generic architecture framework is that, besides multiple systems, which use different technologies, being capable of functioning under the same architecture and interface, they can also work together seamlessly.

In order to support interoperability, i.e. a building location system attempting to use multiple supported technologies, it needs to be capable of including new supported technologies onto its implementation. In order to do so, there are three aspects that need to be fulfilled by the system:

- It has to be capable of functioning with two technologies at the same time. This involves being capable of interacting with beacons from the two technologies. As such, the system has to be capable of communicating with beacons and allow the extraction of their information, for either technology. At the same time, the location server needs to be capable of calculating the user's position independently of the data's type.
- It has to be capable of working with two location calculation algorithms. This aspect enforces the location server to be capable of having two implemented algorithm, both capable of producing a location from the same provided data.
- It has to capable of working with two location description formats. Such condition affects both servers. The location server is allowed to provide locations in one of two different types of formats, while the maps server is capable of providing a map in either. The smartphone needs to be able to display to the user its location, no matter the used format.

Environmental requisites The environmental requirements are independent from the system's technology. GEFILOC's architecture presents beacons as the components responsible of providing the user with information about its surroundings. As such, two beacon requirements emerge:

- Since beacons are only required to communicate with the user's smartphone, which is accomplished through its technology's protocol, no network access is required.
- Since beacons are deployed onto the environment, a crucial requirement is their capability of working without need for maintenance for long periods of time. As such, their energy

consumption should be the lowest possible. If such requirement isn't met, the system's maintenance cost increase.

3.2 Generic Architecture

The solution presented in this thesis was made with the objective of creating a generic indoor location system capable of being implemented and deployed using widely available technologies. Another important concept is the capability of allowing multiple different technologies on the same system to work seamlessly. The generic system's architecture is presented in Figure 3.1 and is divided in 4 parts: beacon, location server, map server and smartphone application.

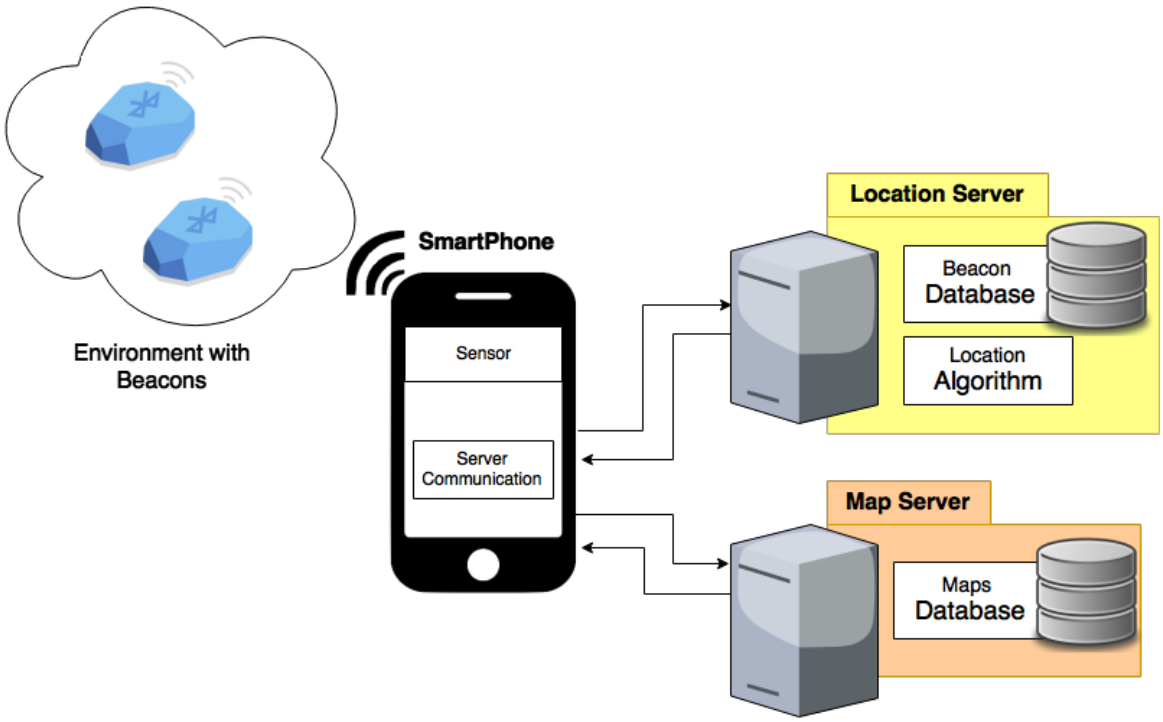

Figure 3.1: Generic System's Architecture

The environment with beacons represents any form of element responsible for providing fixed reference points which are fundamental in calculating a user's position. A beacon needs to be compatible with the smartphone sensor, i.e. the device's sensors need to be able to capture the data. Using the previously presented technologies as examples, these beacons could be in fact BLE enabled beacons , Wi-Fi access points, LED lamps or even sound, with the data capturing being made through the smartphone's available antennas, camera or microphone respectfully. The beacon represents a position in the indoor environments and as such it needs to be uniquely identified, be it through its characteristics or associated information. In addition to these informations, each beacon needs to be assigned to a location server and be capable of handing over its information to the smartphone application.

The location server is an external component where the information relative to the beacons utilised

is stored. As such when a location request arrives from the smartphone, the received data can be translated into physical reference points which will later be used to compute the user's location. Once the location is obtained, two things are sent back to the smartphone: the calculated location and the address of the map server.

The map server represents the architectural block responsible for providing the maps associated to the location of the user, location which was obtained through the location service on the application. The used map representation is up to the system, for as long as it is in accordance with the remaining parts of the system. This means that the location provided by the location server needs to be representable on the provided maps and capable of being comprehended by the smartphone application.

The smartphone application is the central piece of this architecture. It is in charge of discovering and communicating with the beacons existent in its environment through its sensors. This communication process allows the smartphone to obtain information of its surrounding and to obtain the address of the location server that is associated to the connected beacon, in order to later forward this same information to it. Upon communicating with the location server, the application expects to get back information relative to its positions as well as the address of the map server that is to be contacted. Through that address, the application is capable of obtaining the map relative to its positions and display the result to the user.

The presented architecture was structured in a way that it is scalable and allowed for interoperability. The idea behind this architecture is to let different indoor buildings use their own implementation of the system while a user with the associated smartphone application would be able to transit between buildings without changing configuration. This would be achieved through a common architecture that allowed for self-contained implementations to be accessed through a generic smartphone application. In order to analyse this assumption it is necessary to look back on the already analysed Figure 1.1, located on Section 1.1, which represents the main components of an indoor system. The architecture proposes an isolation of the algorithm and location representation, with the intention of having a more flexible system. By making the smartphone the central piece of communication, the beacons are required to be the ones providing the data for location calculation. Through a server dedicated to computing the location of an user, the system developers are allowed to use whichever algorithm they wish, since there is no dependency linked to the application.

3.2.1 Deployment environment

In order to understand how a system based on this generic architecture, Figure 3.1, has to be structured, it is relevant to analyse the system component's description and requirements that would allow it to be deployed.

The smartphone service is the component that is in charge of communicating with both the beacons and the location server. This service is a software component of the smartphone application which is controlled by the app and is in charge of providing the user's location. Once a location is requested by the application, the service initiates discovery with nearby beacons through one of its

sensors. A service is associated with one technology, as such if the application has to support more than one technology, multiple services should be implemented. This condition is fundamental since it allows the service to quickly tag the data with its associated technology, information which must be delivered to the location server. Once the beacon data has been collected, that data is forwarded to a server. Upon obtaining a location from the server, the service should forward the location to the app, which is responsible of later communicating with the map server. In terms of requirements, the service needs to have Wi-Fi or at least mobile network available for communicating with both the location and maps server, and access to the sensor required to communicate with the nearby beacon. In the case of BLE it would be the Bluetooth antenna while for QR it would be the camera.

If one starts by analysing the beacons component, one can describe them as the reference points of the system which are in charge of providing nearby users with information relative to their surroundings. These beacons are available to the users and once contacted should make available to the smartphone the address of its associated location server. Since the beacon only communicates with the smartphone, it isn't required to have any other communication capacity other than that specific to its technology. The communication between the smartphone and the beacon should include enough information to calculate the position.

The Location server should have a database of all the beacons associated to it, each with its exact location of the map. This location is dependent on the method for location description chosen. The server should also be able to handle input from any of the supported technologies and apply the implemented algorithm, so that the user's location is obtained. From this description one can define the requirements of the location server as having stored the beacons that are associated to it as well as their location. The location server must also be capable of communicating with the smartphone application, as well as be in accordance with the map server, achieved through providing location description that is the same as that present in the maps server. Assuming that all requirements are met, the location server should be capable of obtaining a location through its implemented location calculation algorithm.

The Map server is responsible for providing the application with the maps that it has requested. The only decision concerning this server is the type of location description that is to be used and consequently the only requirement is that it has to be in accordance with the information on the location server.

4

Implementation

Contents

In this chapter, a detailed explanation of the implemented system will be provided. Figure 4.1 provides an expanded view of the already presented Figure 1.2. In order to implement the system, several decisions were made. Starting with the beacon, the chosen technology was Bluetooth Low Energy (BLE), leading to the usage of BLE-enabled beacons. This decision is fundamental for defining the software that is to be use for smartphone-beacon communication, in this case being the BLE stack. For the map server, the Google maps service was used, and as such the map service component of the smartphone was implemented through the Google maps API. The algorithm implemented on the location server was a Cell of Origin (CoO), which was described on Section 2.1, that made use of beacon information stored onto a database, for calculating positions. This database is represented by the beacon manager component of the location server.

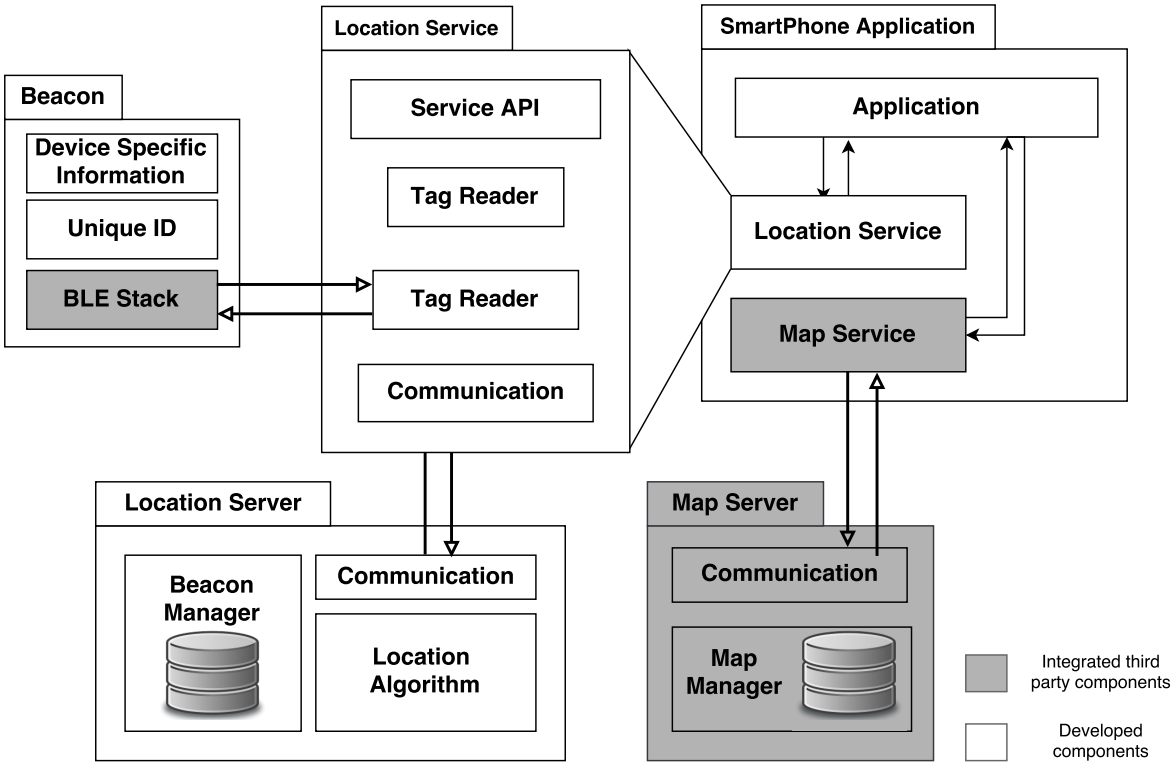

Figure 4.1: Detailed system Architecture

4.1 Location algorithm

The location algorithm is in charge of calculating a position from a set of data that it has received. This data is dependent on the beacons and is formed by a group of pairs of data. Each pair is composed by one of the metrics presented in Section 2.1 and the ID of the beacon associated to it. As such the data that is given to the algorithm is a list of pairs that was collected by the location server.

The deployed algorithm can be of different types, depending on the demanded system's location precision. In this implementation, the chosen algorithm was a Cell of Origion (CoO). This implementation choice allowed for a less complex implementation of the location server, while still being capable of calculating locations. The location algorithm starts by confirming that all the received beacons are

present in its database. Having confirmed that, it analyses the list in search for the highest metric value. The user's location is presumed to be equal to the location of the beacon with the highest metric.

4.2 Beacons

4.2.1 Communication protocol

The used technology on the beacons was Bluetooth low energy, which has already been introduced on Section 2.2. For better understanding the beacon-smartphone communication, it is fundamental to comprehend how this technology works. All the presented information on BLE was obtained from its core manual [48].

The smartphone and the beacon are set up as two complementary classes. The beacon is defined as a peripheral, a role used to describe devices optimized to support a single connection. This role allows it to have a reduced complexity, since it's only required to function as a slave, an entity that is only capable of receiving connections. On the other hand, the smartphone is defined by the complementary role, central. A central device is capable of supporting multiple connections and is responsible for initiating all of them.

Another important aspect in understanding this technology is the BLE profiles. A profile, which can be seen on Figure 4.2 defines an hierarchy in which a device's available services are organized. By doing so, a system's profile ends up defining the applications behaviour and data formats, as well as the manner in which data is exchanged. The hierarchy is composed by two parts: Services and Characteristics.

- A profile is composed by one or more services. A service is a collection of data and associated behaviours 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 being referenced from at least one primary service. A service is composed of characteristics and/or references to other services.

- 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.

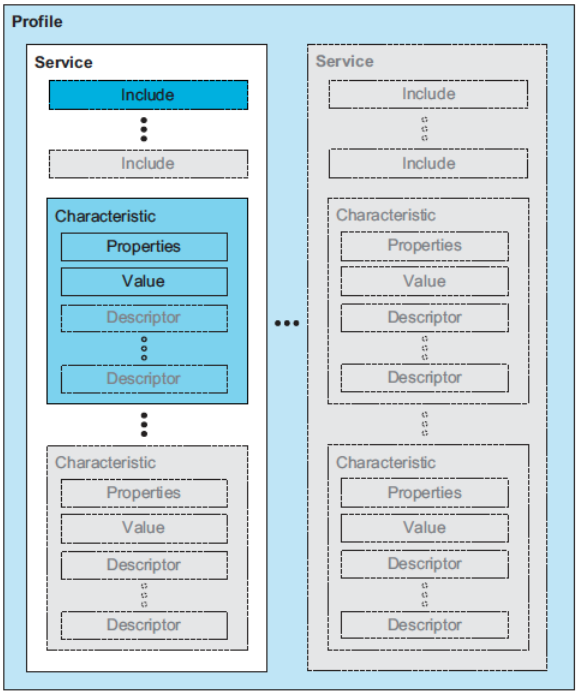

Figure 4.2: Gatt-based profile hierarchy

4.2.2 BLE enable beacons

The used beacons are Texas Instruments CC2650STK devices which can be visualised in Figure 4.3. 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 predefined BLE profile existent on the device could be changed.

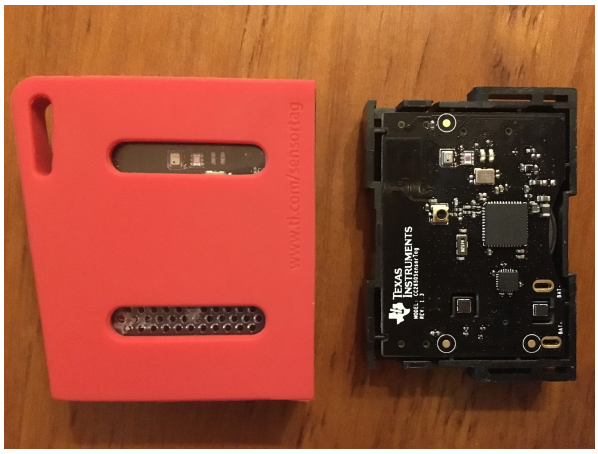

Figure 4.3: TI cc2650stk sensortag

The initial idea was to insert a new service into the already existing profile making use of the generic files provided by Texas. In order to implement the service, a characteristic containing the device's server IP and port was created and two random 128-bit universally unique identifier (UUID) were generated. When using UUIDs, the Bluetooth SIG defined several UUID, each associated with a

certain service, such as heart rate or glucose services [49]. This situation makes it so that whenever one intends to implements a new service, one has to generate a random 128-bit UUID for his service and another one for each of required characteristics. Despite the efforts made, it wasn't possible to alter the existent profile by adding the new service neither by simply attempting to alter it by removing existent services. Due to the low amount of existent information on the technology an alternative was created. The solution found was to store the information into an already functioning service's characteristics as one was capable of altering those kind of parameters. The characteristics available to be used were only the ones from the device information service, a service defined by the Bluetooth sig, since the remaining services on the BLE device were meant for reading values of from sensors. The chosen characteristic was the Manufacturer's name due to its low relevance and the fact that its UUID was known, while the remaining's weren't.

In order to reduce the time complexity of the BLE communication between the tags and the smartphone application, an attempt was made to reduce the number of connection to a minimum. With the objective of only attempting to communicate with tags that belong to the system while ignoring the remaining, a template name was given to each tag. By adding a common name component, such as B̈LE_TAG_SYSTEM_änd adding a second part that is device specific, one attempted to apply an initial filter on the nearby BLE enabled devices.

4.3 Location service

The Smartphone application was developed for Android using the Android Studio IDE. The Application is divided in two primary functional blocks, the location service and maps service, as seen in Figure 4.1.

The location service is implemented as if it was a location provider, such as GPS. By implementing the whole process of obtaining a location inside a service, one extra 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 service and the application only needs to listen for the answer that will eventually arrive.

The location service includes the first three steps presented in Figure 4.4, which will now be described individually. The initial step represents the gathering of information about user's surroundings. Upon receiving a location request, the service initiates a scan for nearby Bluetooth low energy beacon. This scanning puts the smartphone in a listening state for incoming BLE advertisement packets. During this scanning period, each time a beacon is found, its name is analysed so that it can be compared with the used name template. Having passed through the first scanning, each beacon is registered for later usage. Once the scanning period is completed, the list of beacons is completed and forwarded for the next step.

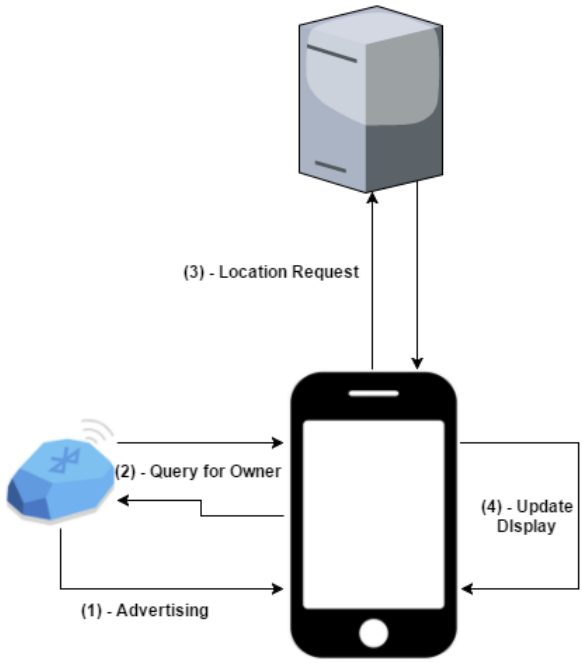

Figure 4.4: Application Workflow

The second step, in a summarised way, consists of communicating with each of the beacons, in order to obtain their location server's address and forwarding the list to it.

Upon completing the first step, the location service communicates with each beacon individually. For each beacon the service will attempt to respond to the caught advertisement packet, so that a connection can be created. Once the connection is created, the service requests a list of the available services of the paired beacon. Once received, the list of services is searched for, in an attempt to find the system service's universally unique identifier (UUID). If the beacon doesn't have the UUID that the service is looking for, it can assume that the paired BLE enabled beacon doesn't belong to the system, leading to the termination of the connection. If on the other hand, the UUID is present, a request for the service's characteristics is made.

Upon obtaining the requested list, its content is examined with the objective of finding the UUID of the characteristic containing the address of the beacon's associated location server. This search has the objective of confirming that the service existent in this beacon is in fact the one that was implemented for the system, thus excluding the possibility of having a different service which 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 service reads its value, i.e. the beacon's associated server address, and stores it in a list. This list will contain the servers of the beacons that were found, and for each address there will be a list corresponding to each beacon's ID and their corresponding received signal strength indicator (RSSI) values. In order to quicken the previously described process, the service could keep in cache the most recent contacted beacons. Upon obtaining a beacon's associated server address, this information could be stored in a cache. Therefore, before initiating

any connection, the service can look up if the beacon's data is present on it. Whenever this search succeeds, no further work is necessary. This optimisation would largely reduce the required number of connections.

When every beacon 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. The voting system was implemented with the intention of providing a thin security layer. Since every beacon has an associated weight, one expects that the sum of valid beacon's weight is capable of eliminating that of a nearby attacker. After calculating each server's weighted sum, the one with the highest is chosen. This server is selected as the one responsible for calculating the user's position.

The third step involves a simple client/server tcp interaction. The service starts by formulating the message that it will later on send to the server. This message includes all pairs of beacon mac address and its associated RSSI value captured by the service on the first step. Once the message is constructed, the service attempts to create a connection with the location server. With the connection established, the message is forwarded to the server and the service is put onto a blocked state where it awaits for an answer. Upon arrival, the received answer is verified, its information processed and the connection is terminated. The information contained inside the received message is then transferred into a container capable of storing a geographic location, which is then passed onto the application.

4.4 Server

The web server was implement in Python 3.5 programming language. The program implements a tcp server capable of receiving multiple request at the same time. Each request starts with information sent from an application which includes an undefined amount of pairs of MAC address and associated RSSI value, each corresponding to a BLE enabled device that was found and connected. Afterwards the list of pairs is filtered in order to remove any existent devices that are not present in the server's database of devices. Upon extracting all the foreign devices from the list, the locating algorithm is deployed. Once the location has been calculated, a message is sent back to the smartphone with its information.

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 can store additional location information such as the server's street, number, zip-code, city and country, allowing it to be transmitted to the client. This offers an additional level of location description to the user.

4.5 Application

The implemented android application is responsible for communication with both the location service, already presented in Section 4.3, and the maps service.

When a user notifies the application that he wishes to start the system, the app starts a periodic operation that provides a location at the end of each iteration. At the beginning of each operation, the app requests the location service for a location. The expected answer contains a geographical location as well as additional textual information. The data is then forwarded to the maps service. This action is the fourth and last from Figure 4.4.

The maps service is implemented using the Google Maps Android API. Through the usage of Google Maps, it was possible to reduce the load on the application, since there was no need implement the maps server component. Since the indoor maps of the testing environment were already available, there was no need to upload addition maps onto google maps. Having passed the entire maps server component onto the already existent service, the complexity of the system was reduced. By making this development choice, the system as a 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 while possible and well documented, is dependent on a third party. As previously described on Chapter 3, upon deciding to use the google maps service as the maps server, the location description present in the location server had to be adjusted accordingly. The position description of each BLE enabled device contained in the database were updated, so that it would be compatible with the description type used by Google maps. This change involved describing each beacon by its latitude, longitude and floor level.

The Fourth step occurs when the application receives a 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 centralised on the position while displaying the indoor level map. The menu visible on Figure 4.6 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 used. The Google API is capable of providing a list of the levels of the building that is currently being focused by the map's camera. Since the location's associated floor is know, the floor can be selected from the list and the view updated.

The pop-up menu was implemented to demonstrate the capacity of providing additional information associated with each location. While the current implementation displays the location's geolocation taxonomy, the architecture is capable of support other types of additional information, such as hyperlink or information on nearby events.

The final state of the implemented system can be visualised in Figure 4.5 and Figure 4.6. The first figure displays the applications main screen, where the google maps view is located. In this example:

- The user's location inside the building is represented by the red marker;
- The building where the user is located is focused. Upon focusing on a building, google maps provides a level selector. Through it, it's possible to select the building floor that is to be displayed;
- The building floor where the user is located is selected. This action updates the view with the

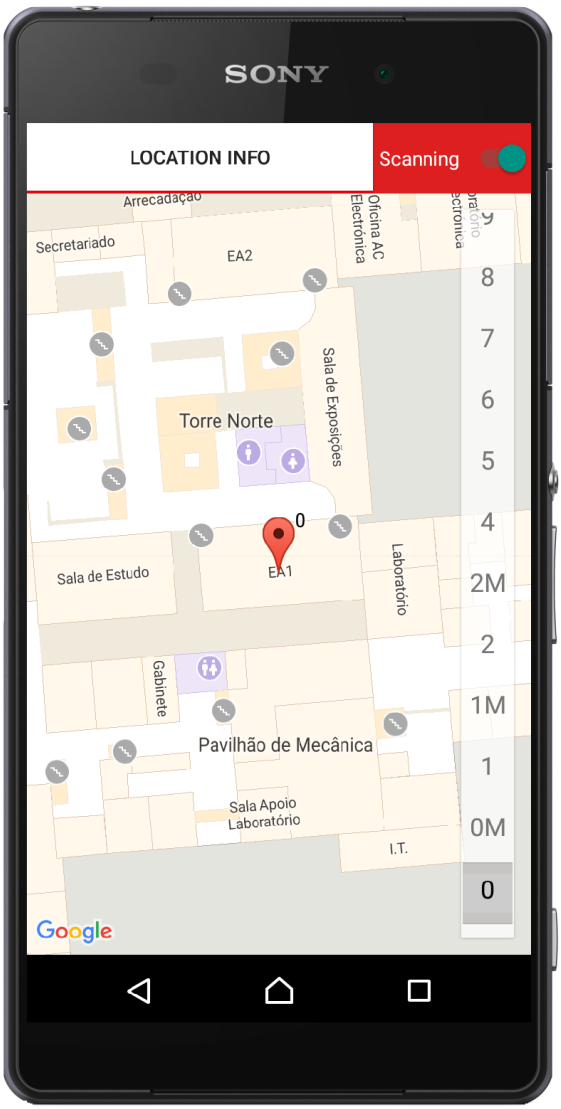

Figure 4.5: Application screen showing a focused location on a room

selected floor and highlights it (floor 0) on the provided menu.

Figure 4.6 displays the menu containing the geo-location taxonomy.

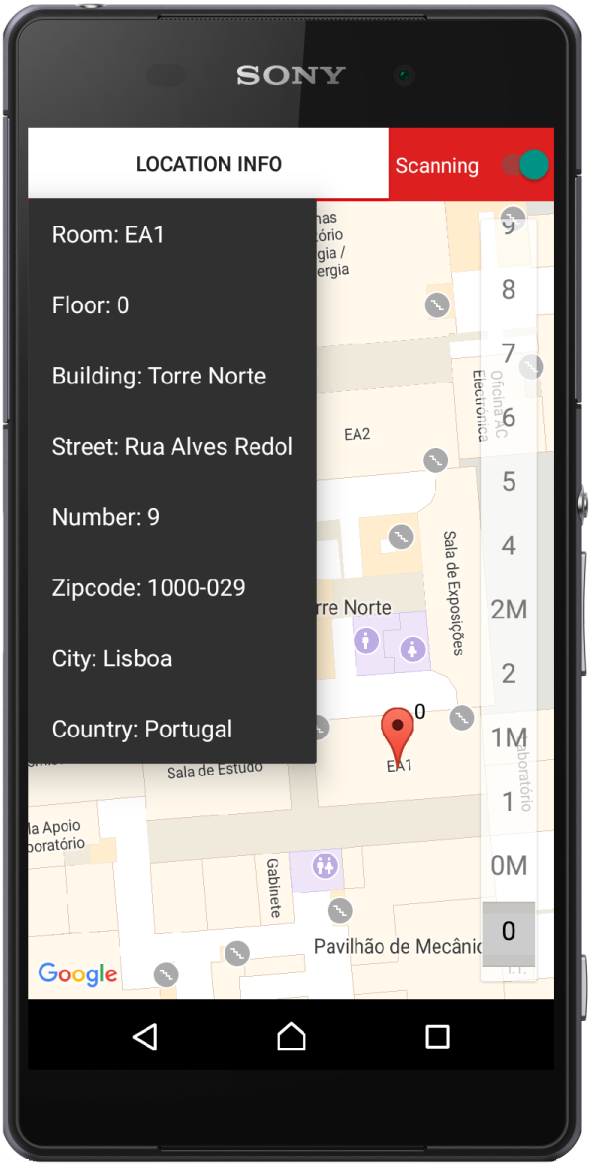

Figure 4.6: Application screen showing additional information of location

5

Evaluation

Contents

5.1 Energy consumption

In order to analyse the energetic costs of the Bluetooth Low Energy (BLE) system implementation, a series of tests were designed and executed. The tests were divided into three categories: system off, system on and system working, presented in Section 5.1.1.

The used smartphone was a Sony Xperia E5, whose battery is rated at 2300 mAh. The battery values data collection was made through the android API, which allows one to know the battery percentage of the smartphone. This API allows one to obtain the current charge of a smartphone in terms of percentage, making it so that this condition imposes a constant error margin on the tests results.

The tests were all conducted under the same base conditions, the battery was completely charged, without a SIM card and with the screen at maximum brightness. They were also conducted over the period of an hour.

5.1.1 Tests

5.1.1.A System Off

With this analysis one intends to understand the energetic cost of a smartphone on standby, i.e. idle and without service, in order to comprehend the baseline consumption and compare it with the energetic costs of the application, in multiple tests with varying factors.

This category includes one single test case, case number 1, and its intention was to analyse the smartphone's energy consumption on standby with its sensors turned off. This case's test conditions were: having Wi-Fi and Bluetooth turned off and leaving the screen active on the main screen.

5.1.1.B System On

In this category one will study the energetic impact of Wi-Fi and Bluetooth on the smartphone device. In order to do so, three tests were conducted: The first one (test case #2, Wi-fi no service), activates the Wi-Fi without having available service; The second one (test case #3 - wi-fi on), activates the Wi-Fi while providing service; and the last one (test case #4 - system active), allows the same Wi-Fi conditions from the previous test (test case #3) while activating Bluetooth.

The last test, number 4, is fundamental, since it will allows for a better interpretation of the system's energy consumption. By providing a value for the energy consumption of the smartphone with everything active but the system, one can obtain more precisely the system operational costs.

5.1.1.C System Working

The system working category studies the energetic impact of the indoor location application on the smartphone. In order to do so, tests were conducted where two parameters were tuned, the number of nearby beacons and the discovery procedure frequency. The discovery period was tuned using four different values, five, fifteen, thirty and sixty seconds, while the number of nearby beacons was either one or two. Using all the possible parameters combinations, eight test cases were conducted.

5.1.1.D Communication Costs

When proposing a generic architecture that is based on isolation of components in exchange for interoperability, it is important to analyse its drawbacks. In this case the isolation is obtained at the cost of higher communication costs, network communication with both the location and the maps server. In order to analyse the impact of this communication six test cases were used where two parameters were tuned: The number of nearby devices, one, two or three devices, and the operation that was carried out. While half of the tests performed the complete operational cycle, the remaining half didn't make use of any network communication, i.e. it completed the BLE communication but stopped right after, before communication with any of the servers. This variations allows one to examine the amount of energy spent on network communications, while studying if there are noticeable differences relative to the number of nearby beacons. All the tests were made using a 5 second cycle period.

5.1.2 results

- The energetic cost's comparison of the three test cases for system on, as well as the one for system off can be seen on Figure 5.1.The presented figure allows one to visualize the overall energetic impact of the smartphone's sensors, which would be around 23 mAh, equivalent to one percent of the smartphone's battery. It is also possible to estimate that the Wi-fi sensor is the one contributing the most for this impact. It is important to keep the results of test case #4 in mind, since it represents the energetic cost of having the smartphone application active alongside all of its required sensors, but without any of its functionalities active. This value in conjunction with the measures of the tests of the system working will allow to identify the costs of the application's functionalities .

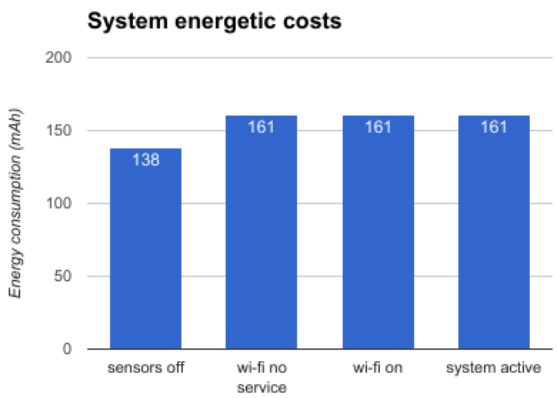

Figure 5.1: Test cases #1-4: System On - energetic costs

- On Figure 5.2, one can analyse the test cases from the system working group. Test case #4 - system active is shown so that it is possible to better visualize the energetic cost of the application. The remaining data is grouped into pairs, with each pair having in common the used discovery procedure period. Test cases #5 and #6 use 5 seconds cycles, cases #7 and #8 use 15 seconds, cases #9 and #10 use 30 seconds and cases #11 and #12 use 60 seconds.

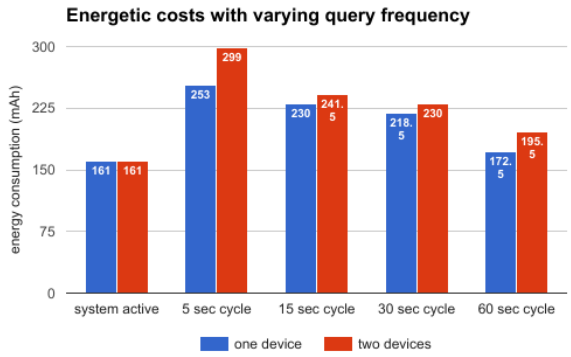

Figure 5.2: Test cases #5-12: System Working - energetic costs

From the figure, one can observe the energetic impact that occurs when adding an extra BLE device for the application to interact with. The existence of more than one device leads to an energetic increase in the BLE communication and as such the cost of this operation is proportionate to the number of existent nearby tags. When passing from one to two available devices, the number of operations is effectively doubled.

Regarding the increase in cost associated to the number of beacons, the value here presented is highly increased due to the lack of optimisation. The insertion of a beacon cache, which although implemented wasn't used during testing, would reduce the cost of the BLE communication operation to practically zero. The reason for this statement is that each beacon has a unique ID and, in a normal indoor environment, the user moves at low speed. Therefore the number of new beacons in each cycle is small. This situation leads to a beacon being heard multiple times, as such saving the server address associated to each beacon makes it so the BLE communication query is required only once. By saving the information of the most recently contacted beacons, the number of required operations is proportional to the number of newly discovered beacons, instead of the number presented in these tests (equivalent to 1/2 new beacons in each cycle).

- Figure 5.3 presents the results for the communication cost analysis. It is possible to confirm that the network communication costs associated to the system are almost independent from the number of devices, having reached a flat cost of one percent of the phone battery in this case. This value can be interpreted according to the low amount of information that is being transmitted in each packet, i.e. each beacon's address and associated Received Signal Strength Indicator (RSSI) value, that relative to the packet header isn't impactful when communicating with the location server. The remaining messages are the answer from the location server to the smartphone, which has a constant small size (location information), and the messages to and from the maps server, which in this case is made through the google maps API and it is of relative constant size independently of the number of beacons.

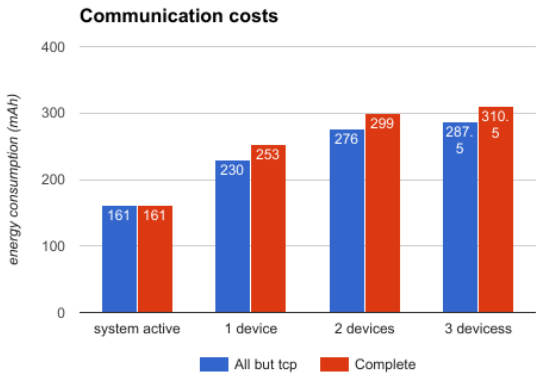

Figure 5.3: Communication's Energetic cost

- Making use of the previously presented test cases, it is possible to obtain the average cost of network communication. The packet's average cost value and its intermediary values for calculation are present in Table 5.1. Since the number of used packet during the test is capable of being calculated, the cost associated to each of them is also possible to calculate.

Nº cycles / 1 hour	720
Nº packets / cycle	4
Communication Cost	23 mAh
Average packet cost	0.008 mAh (1/2880%)

Table 5.1: Packet's average cost

Overall the added cost caused by externalising both the maps and the location component into servers is low. This energetic impact is still not representative of the actual network communication cost of a real system deployed according to the proposed generic framework since there are optimizations that aren't being taken into consideration. An example of an optimisation, would be achieved through the usage of the accelerometer or any other sensor capable of detecting user movement. When capable of detection such event, the system would avoid requesting the user's location until movement occurs. This optimisation would be capable of reducing the overall system consumption.

5.2 Integration with Google Maps

The integration of Google maps onto the system allowed one to create additional features, that aren't available through its commercial service. The Google maps service has limited functionalities for indoor locations. Their functionalities are limited to providing the maps for each floor of the building, providing the possibility of selecting the floor that the user wishes to view and selecting the whole building, which presents the general information relative to it.

One of the lacking capacities in our view, is the possibility of selection, i.e. showing markers, within the indoor map. Through the implemented system, this is possible since whenever the location of the user is displayed, it is done through a marker within the indoor map. Another functionality that

is provided by the system is the ability to display the user's position on the correct floor. With the Google maps application, even when a building has an indoor map available, the user's position isn't displayed according to its altitude. In a situation where the whole building would be covered by the implemented system, a correct display of the user's movements could be provided.

Although the accuracy provided by the implemented system is only room-based, its capable of being improved. Thanks to GEFILOC's architecture, the operation of exchanging/inserting a location algorithm is simple. As such a brief description of how it would be accomplished will be provided.

The deployed algorithm can be of different types, depending on the demanded system's location precision. Taking a triangulation algorithm as example, one will now explain the steps required to calculate a position, which can also be seen on Figure 5.4. The location algorithm starts by analysing each pair of data individually. For each pair, the ID contained in it is searched for into the beacon manager, so that the received metric can be associated to a physical location. Once the procedure is completed, a complete map of the reference points and their associated distances to the user is obtained. Using the obtained map, an estimation of user's location can be calculated from the three available points. Due to the simplicity of the example, no additional work was conducted.

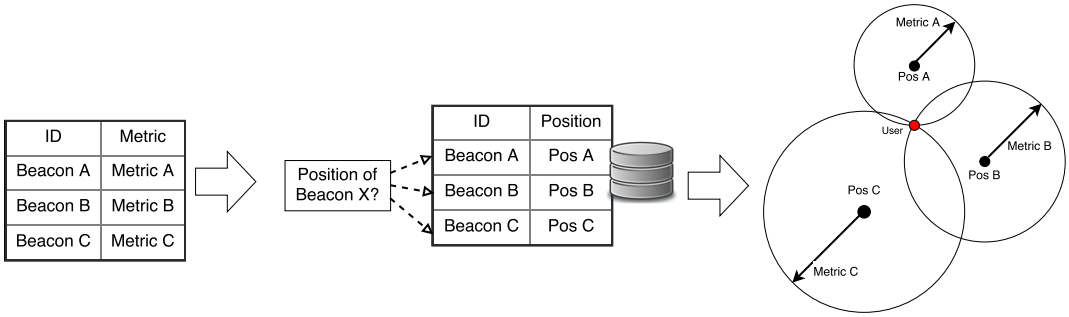

Figure 5.4: Location algorithm's calculation procedure

6

Conclusions

The work developed throughout this dissertation presents a generic framework architecture for indoor location systems. In order to better understand this technological field, a study around the existent work was conducted. Through it, the extensive broadness of available solutions was displayed. From the research conducted, one was capable of noticing the variations of each technology.

This situation was mostly caused by timings at which revolutionary projects, as the ones seen in Chapter 2, were presented to the public, shifting the opinions of which technology would be the most suited to lead the field. As such, no technology has been declared the winner mostly due to the particularities of each and the differences among them. Meanwhile, mobile devices evolved from devices capable of making phone calls to small computers capable of incorporating a wide variety of sensors. This progress granted indoor location systems, a universally-used mobile device equipped with sensors compatible with some of the indoor location technologies. Such progress allowed systems to never again be required to develop their own system-specific devices, effectively reducing their associated costs and increasing their overall accessibility. There were still several technologies that took benefit from smartphones, as there wasn't one capable of being largely better than the others. Instead of further dwelling into the field, one decided to take a more generic approach, through the proposed generic framework architecture, we intended to make use of the smartphone capacities to bring together technologies into one common platform.

The main design concerns of the generic architecture were that it would be scalable and that it would be capable of embracing any existent indoor location technology. Another concern was to have an architecture capable of being adapted to each possible variant of algorithm, the one used for the location calculation, and location representation.

This capacity was achieved through the offloading of the location computation and the location representation, the component responsible for displaying to the user its location. By isolating each component into their separate server, new considerations were imposed that were not present in previously developed systems. Firstly, with the externalization, a new layer of network communication would be required, which although it's available to all smartphones through Wi-Fi or mobile data, has its own cost that is required to be evaluated. Nevertheless, the trade-off for these extra costs was the possibility of removing the location algorithm dependency from the smartphone, as well as the location description dependency.

Having the location algorithm outside of the smartphone carries many benefits, such as facilitating the deployment of the system. Since the algorithm is required to know the position of each beacon that is associated to the system, the updating of that collection of information is passed onto a server, instead of requiring an update on each mobile device. Another important aspect is the possibility for users to benefit from systems with different algorithms, since the mobile application isn't tied to a local algorithm, the usage of a different system is simply tied to making a request to a different location server.

One of the objectives that the generic architecture attempted to achieve was extensibility, to provide a framework where an additional technology, algorithm or location format could be inserted. As discussed in Section 3.1, where the interoperability requirements were presented, a system based on

this architecture can make sure that such addition is possible.

Having defined the generic architecture, GEFILOC, an implementation was achieved through the usage of the Bluetooth low energy technology and the Android operating system. In this system several components of the architecture were implemented: BLE-enable beacons, each programmed with their specific information; a location server, with a database containing the used beacons and a Cell of Origin (CoO) location algorithm for location calculation; and a smartphone application, with a location service responsible for communicating with the beacons and the location server. For the maps server, the Google maps service was used and as such, its API was used to implement the map service component of the application.

With an implemented system, it was possible to investigate its energy consumption. A batch of tests was conducted with the intention of understanding the costs associated to the system. It was possible to obtain the value for the system's idle consumption, as well as for when all the system's required sensors are active. From these initial tests, it was possible to understand that the Wi-Fi sensors had the highest impact on consumption and it was possible to obtain the smartphone's base costs, an important value for better extracting the system's associated consumption.

The second group of tests was thought out with the intention of understanding how the system's consumption evolved, through the tuning of two factors: the number of nearby beacons and the operation cycle period. With these results it was possible to visualise the impact of the BLE communication, since changing the number of beacons only has a significant impact on the BLE communication. Through the tuning of the operation cycle period, the energy consumption reduction associated to it was verified to be in order with the expected.

The last batch of tests was conducted with the intention of evaluating the costs associated with the network communication. This was an important evaluation, since this cost was caused by the architectural choices of isolating components onto servers. As such, tests were created through the tuning of two factor: The number of nearby devices and the operation executed. For each number of nearby devices, one test performed the complete operation as normal, while the other stop immediately after the BLE communication, meaning that no network communication was performed. From the results, it was possible to understand the reduced energy consumption associated to network communication. This analysis supports the decision taken, since the trade-off for isolating the components came at a reduced cost.

Overall the energetic costs associated to the implemented system support the decisions taken on the architectural design. The most relevant cost was the one associated to the network communication, since it came as a trade-off for the scalability, which achieved acceptable values.

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