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# Mobile ticketing using Bluetooth low energy technology

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Mestrado Integrado em Engenharia Informática e Computação

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# Abstract

Public transport play an important role in most cities, and even more in large cities. Over the last few years, we've seen some cities taking measures in order to reduce the number of cars on the streets, and make people use public transportation. This evolution of the way people commute and move around cities, associated with the technological evolution of current times, would benefit from a solution that could motivate more people to use public transports, by making the ticketing and validation processes easier and simpler.

The fast spread of mobile payment solutions, and its acceptance by the population, provide an opportunity to apply this idea to public transportation. The solution this thesis proposes will also take advantage of Bluetooth Low Energy (BLE) beacons, which are currently compatible with most mobile devices (with Bluetooth capabilities), and are expected to become even more accessible and with better performance in a near future.

The solution presented is a platform which the users access via an application on their mobile devices, and that is integrated in an intermodal public transportation network (including bus, light rail and train) that works as a *check-in/be-out* system. The way the mobile application works is by using the Bluetooth technology on the smartphones to detect BLE beacons, which are installed in the vehicles (buses) or stations (light rail and train), and that allow the tracking of the users' trips from start to end. This platform also suggests the implementation of post-billing with the integration of a tariff optimization algorithm based on each user's monthly trips. This process requires minimal input from all the parties involved, resulting in a smoother experience either for the user, and for the transport operators, making public transportation more appealing to everybody.

The main focus of this work is to evaluate the viability of the use of BLE beacons in real world scenarios, where all wireless communications are subject to interferences by other devices. Besides the description of a platform that takes advantage of the use of BLE beacons as part of a mobile ticketing system, also the challenges of the process, along with the testing methodologies and results are described. The validation of the solution is integrated in a pilot study conducted in Porto.

# Resumo

O sector dos transportes públicos tem um papel importante na maioria das cidades, algo que se evidencia quanto maior for a sua dimensão. Ao longo dos últimos anos, várias cidades tomaram medidas no sentido de reduzir o número de automóveis a circular nas ruas, e incentivar a população a utilizar os transportes públicos. Esta evolução da forma como a população faz as suas deslocações diárias e viaja dentro das cidades, associada com a atual evolução tecnológica, beneficiaria de uma solução que conseguisse motivar a população a utilizar os transportes públicos, através de um processo de compra e validação de bilhetes mais simples e de fácil utilização.

O rápido crescimento de soluções de pagamentos móveis e a sua aceitação pela população constituem uma oportunidade para utilizar este conceito nos transportes públicos. A solução proposta nesta tese toma partido do uso de beacons Bluetooth Low Energy (BLE), que atualmente são compatíveis com quase todos os dispositivos móveis (com tecnologia Bluetooth), e espera-se que se tornem mais acessíveis e com melhor desempenho num futuro próximo.

A solução apresentada é uma plataforma a que os utilizadores acedem através de uma aplicação nos seus dispositivos móveis, e que se integra numa rede intermodal de transportes públicos (que inclui autocarros, metro e comboio) e que funciona através de um sistema *check-in/be-out*. A aplicação móvel funciona através do uso da tecnologia Bluetooth nos *smartphones* para detetar beacons BLE, que estão instalados nos veículos (autocarros), ou nas estações (metro e comboio), e que permitem o acompanhamento das viagens dos utilizadores desde o início até ao fim. Esta plataforma também sugere a implementação de pós-pagamento integrado com um algoritmo de otimização de tarifário baseada nas viagens mensais de cada utilizador. Este processo requer interação mínima por parte de todas as partes envolvidas, resultando numa experiência mais simples quer para o utilizador, quer para as operadoras, tornando os transportes públicos mais atrativos para todos.

O principal foco deste trabalho é a avaliação da viabilidade do uso de beacons BLE em cenários reais, onde todas as comunicações *wireless* estão sujeitas a interferências por parte de outros dispositivos. Para além da descrição de uma plataforma que tira partido do uso de beacons BLE integrados num sistema de bilhética móvel, também os desafios do processo, assim como as metodologias de teste e resultados são descritos. A validação da solução proposta está integrada num estudo piloto conduzido na cidade do Porto.

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João Bandeira

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# Abbreviations

| | |
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| API | Application Programming Interface |
| BLE | Bluetooth Low Energy |
| MVC | Model-View-Controller |
| NFC | Near Fiel Communication |
| QR | Quick Response |
| RFID | Radio-frequency identification |
| RSSI | Received Signal Strength Indicator |

# Chapter 1

# Introduction

## 1.1 Context

The smartphone revolution influenced the way people live by majorly changing several aspects of their daily life. A smartphone is, currently, the center of everyone's digital life: all their contacts are there, they are the main means of communicating with others, whether it's by a simple phone call or SMS, or even if it is through one of the many communication apps out there. Social media is heavily based on the mobile usage of its users. The increasing size of smartphone screens also make them an acceptable form of entertainment, caused by the pleasant experience they allow, whether it is watching short videos, or even longer TV shows. Even in the enterprise market, mobile devices can be used to manage the daily life of business people due to their increased reliability and diverse tool offer.

The increased reliability of smartphones, and mobile technology in general, caused some services that weren't very likely to be adopted by most users before, to start being a standard presence in smartphones. Examples of these services are banking applications, which are made available by a large number of banks, and that give the users the commodity of making bank operations on the move. Alongside banking applications, there is another related area that starts to thrive among smartphone users, which is mobile payments. Mobile payments have seen major advances in the last few years, and solutions like Apple's Apple Pay [App], and Google's Android Pay [Goob], which are already available in some countries, are changing the way some transactions are made.

The sector of public transportation has major importance in most cities, and mostly in big cities. In the last few years, several governments already have, or plan to take measures to lower the number of vehicles that circulate in major cities, mostly because of environmental concerns. Examples of these policies are London's congestion charge [Traa] (which consists in a fee all drivers must pay in order to be allowed to circulate in some areas of the city in specified hours in weekdays), Lisbon's restriction of circulation of cars registered before the year 2000 [dL], or Paris' license plate based restrictions (imposed when pollution levels reach high levels) and plans to forbid circulation of diesel vehicles based on their manufacturing date [Cle16]. These measures and the growth of the cities have direct impact on public transportation, giving the sector a greater importance and making it essential for the sustainability of the cities.

## 1.2 Motivation

The growth of mobile payment's reliability, and acceptance by the population, associated with the need of public transportation to grow its infrastructures make an interesting opportunity to integrate both.

Mobile ticketing solutions for public transportation have been around for a while, and some companies are already exploring this market [Mas], but there are still many public transportation systems that don't offer any mobile ticketing options, which is the case of Porto's system.

Having a platform that allows users to buy tickets and manage their expenses using their smartphones is a concept that brings many advantages for both users, and operators. For the users, the convenience of not having to wait in queues to buy tickets, and not having to carry either a single subscription card or even multiple single tickets are the most evident benefits. For the operators, a lower stress on the whole ticketing system means lower costs to support it, such as ticketing terminals purchase and maintenance.

## 1.3 Goals

This dissertation is integrated in a project whose goal is the development and testing of a platform that will allow its users to use public transportation and enjoy the benefits of a mobile ticketing system with a seamless interaction. To achieve the most seamless experience for the user, the ticketing system aims to require minimum input in the whole travel process. This is achieved with the use of BLE Beacons installed in the vehicles/stops which, by being detected by a mobile application installed on the users' smartphones, allows for an automatic trip recognition. To ensure the viability of this proposal, the effectiveness of the beacons' detection by the mobile devices must be tested, not only in a controlled environment, but also in real world conditions, where these wireless signals are very prone to interference from other devices. The usage of the beacons to know exactly where each user enters and leaves the vehicle is of great importance in order to make this platform compatible with complex zone based public transportation systems, such as Porto's. Porto's case should be mentioned because said platform is being developed to operate in Porto's intermodal public transportation system.

The main focus of this dissertation is then to explore BLE beacons technology, and ensure that their detection is possible and almost immediate in real world conditions, where their operation is subject to interference and even physical barriers that limit the propagation of their signal, and also where the system may be subject to stress conditions due to multiple users being active simultaneously, among other factors. After evaluating the BLE beacons' performance in the desired usage conditions, it is possible to give a verdict on whether the technology is able to be used on a ticketing solution, and provide a valid alternative for the current ticketing systems. To make these assessments, it is necessary to design and develop testing methodologies that allow the measuring of the performance of the proposed solution. This testing process will be integrated with the aforementioned pilot test of the platform in the city of Porto.

# Chapter 2

# Literature Review

## 2.1 Technologies

### 2.1.1 Bluetooth Low Energy

Bluetooth Low Energy (BLE) is a technology that has an important role in this project, and that has had many developments and increased its adoption in the last few years.

BLE was integrated in the Bluetooth 4.0 Specification [Blu10], introduced in 2010 by the Bluetooth Special Interest Group. The main feature of BLE, and that differentiates it from the standard Bluetooth specification, is the low power consumption it allows, making BLE ideal to be used in Bluetooth beacons.

After BLE's introduction, its adoption in the market was very quick [TAD14]. This can be explained by the timing of the launch of the technology, which coincided with the emergence of smartphones and tablets. Bluetooth technology is included in almost every one of this devices because of the small cost of implementation. Since virtually every device available today was manufactured after the introduction of Bluetooth 4.0, most of them are suitable to use with BLE technology.

### 2.1.2 Bluetooth Low Energy Beacons

Beacons are wireless devices that are associated with the broadcast of a signal. Different beacons may transmit different types of information, either static, such as simple identification data, or dynamic, such as information provinient from sensors (temperature, humidity, location, orientation, or others) [Lin15].

BLE beacons implement this by using BLE technology. The signal broadcasted by the BLE beacon can be picked by any Bluetooth enabled device within the emission range of the beacon. The data packet transmitted by BLE devices follows a pre-defined format, described by the Bluetooth Core Specification.

Communication between BLE beacons and other devices can either be one-directional, or connection based. In one-directional communications (connectionless), the two parties involved are defined as the broadcaster and the observer:

- **Broadcaster** - non-connectable device only with advertising capabilities. Broadcasts a simple data packet.
- **Observer** - device that scans for broadcasters' advertisements, without connecting to them.

For connection-based communication, there are also two categories of devices involved:

- **Peripheral device** - works in a similar fashion to the broadcaster, but allows connections to be established, in which it acts as a slave.
- **Central device** - similar to observer, but takes initiative to start connections with peripheral devices, acting as a master.

BLE beacons' role in the communication process fall under the broadcaster and peripheral categories, while other devices, such as smartphones or computers, perform the observer and central device's tasks.

While both communication forms (connectionless and connection based) have its advantages, following a connectionless approach will allow for a more seamless experience, and to achieve the lowest power consumption possible.

The low energy required by BLE beacons makes them very easy to deploy in various locations, because they can be powered by many different power sources, such as USB power supplies, or small coin cell batteries. According to Gomez et al [GOP12], the theoretical battery life of a BLE beacon can range from 2 days, to 14 years, depending on the interval between connections (tested beacons were equipped with Texas Instruments CC2540 Bluetooth chip, and were powered by a common coin cell battery, ∼230mAh). For connection intervals over 1000ms, the battery life is reported to be in the range of one to several years.

**Protocols** There are currently two protocols available for Bluetooth beacons: iBeacon and Eddystone. These protocols are well described by Arvidsson et al [AV16].

iBeacon was the first beacon protocol to be developed, and was introduced by Apple in 2013. Beacons using this protocol transmit a single packet which contains some protocol specific information, and three different values: an identifier (UUID), a Major and a Minor values (16, 2 and 2 bytes, respectively [App15]). These three values identify each of the beacons: the UUID is a large number in order to make its uniqueness highly probable, and usually linked to an application or platform; the major and minor values range from 0 to 65535 and are used to divide the beacons in regions, and identify each beacon, respectively. The proximity of a beacon is calculated using the RSSI value. High RSSI values mean the beacon is nearby, but low values can't confirm how distant the beacon is.

Eddystone was introduced in 2015 by Google as an alternative to the iBeacon protocol. Its implementation is similar to Apple's iBeacon, but has some extra features, and also has the advantage of being completely open source. Eddystone beacons can transmit three different frames:

- **UID** - Similar to iBeacons data frame, allows for advertising beacons to be detected by mobile applications.
- **URL** - Transmits an URL that can be opened in mobile devices, and is supported by Google's web browser, Chrome.
- **TLM** - Used to transmit data from sensors, such as battery power, coordinates or temperature

On one hand, iBeacon is a more mature protocol, with more documentation and simpler implementation, but has less features. On the other hand, Eddystone provides a more flexible protocol which allows to send more information, has more features, but its implementation is more complex.

**Applications** There are several different use cases for Bluetooth Beacons, but most of them are related to location. The more evident use for beacons is indoor location services. By deploying several beacons in a limited space, any Bluetooth enabled device can calculate its position based solely on the signals from them, by using adequate algorithms.

Although beacons are mainly used for location tracking, it is important to note that the tracking is not done by the beacons themselves, but the user's application/device. Beacons act only as broadcasters of a signal, and usually don't even connect with other devices.

**Location with Beacons** As stated before, the main application of BLE Beacons is tracking algorithms, from simple proximity detection, to more complex indoor localization services.

Ranghavan et al [RA10] described an algorithm to accurately locate robots ($0.427 \pm 0.229$m error) using Bluetooth beacons. The algorithm used was based on trilateration, which uses at least three different distance measures to calculate the current location of an object. The distances used in the trilateration algorithm were obtained by placing several beacons in the area of operation of the robots, and then calculating the distance from the robot to each beacon in range, by using the RSSI from each one. This measure is the power level of the received Bluetooth signal from the beacon. To get the least possible error in each of the measures, the authors analysed how the RSSI value varied according to the distance, and even how it varied when the target was not moving.

In 2016, An et al [AC16] presented an algorithm which works different than most localization algorithms with Bluetooth that consists of an Inverse Fingerprinting. Fingerprinting is the method most platforms use to calculate positions, and consists in collecting data from fixed devices, and making the necessary calculations to get the location of the moving device. In the inverse fingerprinting method which is described, the moving object is the one broadcasting a signal (BLE signal), which is read by several devices spread in the target space (the authors tested the algorithm with Raspberry Pi computers, equipped with Bluetooth dongles compatible with BLE). These readings are then sent to a central server, which makes the necessary calculations to locate the mobile device, and sends it this information. The main advantage of this approach is that it frees the user's device of potentially complex calculations and constant polling of beacons' data, leading to much less impact in its battery life. The authors conclude that this algorithm is viable, having achieved an error very similar to traditional fingerprinting algorithms error, while maintaining minimal power consumption in the user's device.

### 2.1.3 Mobile Payments

Mobile payments is a concept that has been evolving recently, and is today widely available through several different platforms and mobile applications. The two main platforms that enable users to make mobile payments are Apple Pay and Android Pay, which are both very widespread because of their native integration with, respectively, iOS and Android devices that support NFC.

**Apple Pay** Apple's protocol was introduced in October 2014, and its presentation described it as an easy, secure and private way to pay using a smartphone [App]. Apple Pay allows the user to associate his credit card to the Apple Pay account, and later use it to make payments with his smartphone, removing the need to carry any bank card. Apple has partnered with several payment networks, such as MasterCard and Visa, to ensure maximum compatibility with the users' cards. Apple's platform allow for two different types of payments. The user can either use it to make payments online, such as in the iOS application store or in the web, or to make payments in physical locations equipped with compatible payment devices. In the case of the physical payments, the user only has to hold the smartphone near the reader, and the payment will be completed. In both cases, the payment is validated using the user's fingerprint.

**Android Pay** Google's approach to mobile payments, Android Pay, was launched in September 2015 [Goob], and is an evolution to Google Wallet, a payment platform that allow money transfer between users, either business or private. This platform is very similar to Apple's regarding its way of use, which consists on associating the user's credit or debit card to their Android Pay account, and allows both, online payments and *on-site* payments in retailers with compatible payment terminals, also taking advantage of mobile device's NFC capabilities. The main feature of Android Pay is its focus on security, and its different approach in the payment process. Instead of transmitting the user's bank card details, Android Pay creates a temporary virtual card for each transaction, creating an extra layer of security.

## 2.2 Related Work

Over the time, several proposals of mobile ticketing have been described, using different possible methods to communicate with the public transportation environment, such as QR Codes, Bluetooth, NFC and others. Some of these proposals are described in this section.

### 2.2.1 NFC

Singapore's public transportation ticketing uses a single card that can be used across several different transports, such as buses, trains or taxis [EZ-b]. This card works as a contactless device which can be topped up with money to be used in public transportation tickets. The main difference between this and other unified systems is that EZ-Link works not only for public transportation, but also as a payment method at food outlets, shopping outlets, government services or vending machines, among others [EZ-c]. The advantages of this system rely essentially on the fact that it makes transactions quick, convenient and secure, while aggregating several services in a single card. In March 2016, EZ-Link started supporting all the features of the smartcard through NFC enabled phones, only requiring the use of a specific SIM card [EZ-a]. This new option shares all the benefits of the EZ-Link smartcard, and makes it even more convenient by ditching the need of the card, which is now possible to emulate with the users' smartphones.

In London it is also possible to ride public transportation using only a smartphone. Since 2007, Transport For London (TfL) has been studying how contactless technology could be used in London's public transportation platform. Back then, a pilot was conducted with five hundred daily users of the Oyster card (smartcard introduced in 2003 that can be topped up with tickets or travelcards) [Tra07]. More recently, in 2014, TfL introduced the possibility of users to pay for their rides with contactless payment methods [Ric14]. Although this was already possible in London buses, by using contactless credit cards, it now supports payment using mobile payment technologies such as Android Pay and Apple Pay, across all the TfL services [Trab]. As this method doesn't allow users to have travel passes, a system fare capping system was implemented for users using contactless payment services. The capping works on a weekly basis, and establishes a limit on the amount a user spends on his Monday to Sunday journeys. This allows the user to always pay the minimum amount for his tickets, according to his usage. If a user travels a lot, he won't be charged above a predefined limit, and if he makes few journeys, single tickets will be charged. The capping assures the user that during the week, the amount that will be charged will never be more than a *7 Day Travelcard* [Trac]. London's approach to mobile ticketing on public transportation has the advantage of offering tariff optimization for the user, which is a factor that can attract many users to the platform, because the capping allows the users to benefit from the best possible price, while not having to make any plans regarding the public transportation use and ticket purchase. The fact that it uses third party services to handle payments, is both an advantage, because leads to less costs in platform development, and a disadvantage, because makes the system dependant on these third party services, making it necessary to keep the infrastructure compatible with them.

Chicago also has a system based on a smartcard for public transportation ticketing: Ventra. Ventra allows its users to top it up with passes for trains and buses. The account associated with the smartcard is managed via an online interface, and passes can be bought in several physical locations, online or by phone. The tickets are used by just tapping the readers in the vehicles. Ventra also offers the possibility to use the card as a debit card, which is accepted everywhere that also accepts MasterCards. The methods available for ticket purchase are also suitable to make deposits on the Ventra card, and withdrawals can be made in ATMs. Instead of a dedicated Ventra card, users can also use their contactless bank card and have the benefits of the smartcard just by tapping it in vending machines or participating retail locations. Besides bank cards, Android Pay and Apple Pay also compatible with the platform, making every Android or Apple devices with this technology suitable to be used in the Ventra platform. Ventra's main advantage for the user is its versatility - users can use Ventra smartcards, contactless bank cards, or even their smartphone to travel in Chicago's public transportation [Chi].

NFC4Sure [ALP+16] is a proposal that describes a complete platform that allows users to buy public transportation tickets on their smartphone, and also the process of validation of the ticket (using the smartphone's NFC capabilities), from the smartphone to the server side. The proposal describes a process that requires the user to validate his ticket in the start, and in the end of the journey, and also describes the process ticket purchase and inspection during trips. One of the characteristics of the platform described is the focus on security, in order to prevent fraud. The system would work the following way: the user uses the mobile application to buy the ticket for the trip he plans to make (in the near future), and the device will ask the user for authentication on the platform (no specific algorithm is described, but a secure authentication mechanism, such as a password based method over a TLS channel, is preferred). After verifying the user's authenticity, the server will generate a token, which will then be sent to the user, encrypted along with the decryption message. The encrypted message received by the user is encrypted twice: one of the steps of the encryption is based on the user's password, which makes it decryptable at the user's device, and the second step is based on a key only available at the validators and at the main server. This algorithm ensures that the token is only readable by legitimate validators.

### 2.2.2 Bluetooth

Although there are already some proposals regarding the use of Bluetooth technology in public transportation, this is not the most frequent approach to the problem. Below are described some of these proposals.

Arvidsson et al. proposed a public transportation ticketing system based on the use of Bluetooth beacons [AV16]. The proposal suggests the use of beacons using the Eddystone protocol, installed in multiple places, not only in vehicles and stops, but also in points of interest inside the stations. The application proposed would generate a persistent notification on the user's device when the user was near a stop, or inside a station. This notification wouldn't make any sound, or alert the user in any way, but also couldn't be dismissed, to allow for easy access to the application every time a user was near a stop or station. One of the strong points described by the authors is the context awareness of the application, and the increased quality of information that this can give to the user. By detecting all the nearby beacons, the application can tell the user which points of interest of the station are in the zone, such as coffee shops or information offices, and also relevant information about the vehicles that will arrive or depart in that station, such as timetables. During the trip, it would also be possible to give updated information about the itinerary, specifically a list of the stops of the route, and where the user currently is, by analyzing which stops have already been detected. The ticketing model proposed is a *pre-paid* model, in which the user only has to specify the end point of the trip, since the start point can be detected by scanning nearby beacons. By asking the user to specify the end point, the application becomes compatible with complex public transportation systems with different prices for different trips along the same route.

Kahvazadeh also proposes an approach based on the use of BLE beacons [Kah16]. This proposal suggests the installation of BLE beacons in all vehicles (buses and trains), which are used to track the start and end points of the trips. Each trip initiates with the user using the smartphone application, and confirm the trip start point, automatically suggested by the application after reading the vehicle beacon's signal. The application ends the trip when the vehicle beacon is no longer detected. This platform calculates each journey price after the fact, and the bills are sent to the user via email or phone text, which is only possible because the operation of the platform is user account based. This proposal outperforms most mobile ticketing solutions because suggests a process that requires minimum user input, but only describes cases where the beacons are installed in the vehicles, which is not always possible.

### 2.2.3 Other solutions

All the proposals explored before were based in the most traditional approaches in communication among mobile devices. The following proposal offers a viable alternative to NFC, Bluetooth or QR Code based approaches, while keeping the system functional and with all the benefits of the other proposals. HopOn is a ticketing system that is in use in Israel, and its operation is based in communication using ultrasonic sound waves. The system's main interface with the users is a mobile app that the users must install on their smartphones. When entering the vehicle, the users only have to tell the app to get a ticket, and the app will communicate with the HopOn beacons and automatically buy the ticket. By using sound waves to communicate, and only needing to use the speakers and microphone of the devices, the app becomes compatible with every smartphone on the market running the supported operating systems (Android, iOS and Windows Phone). HopOn claims that other technologies have several disadvantages: NFC has comparatively low device compatibility, and high equipment cost; QR Codes are inconvenient to use, and also have high equipment cost; and Bluetooth has more impact in the user devices' battery. In short, HopOn's main features are the lower costs of implementation, and the possibility to make several simultaneous validations. This service is currently working on buses, trams, trains, metros and bicycle sharing [Hop]. The approach HopOn's platform proposes has given the company Verizon's Powerful Answers Award 2014, New York City award for "Most relevant transit app", and the first place in the Amazon AWS Tel Aviv summit 2014 [Tar15].

# Chapter 3

# Porto's public transportation

The main goal of this project is to evaluate the viability of the use of BLE Beacons in a mobile ticketing system for public transportation. In order to validate this proposal, this dissertation is integrated in the context of a project which aims to develop a mobile ticketing platform that is compatible with the existing public transportation system of Porto. Having this in mind, it becomes interesting to make a closer analysis of how Porto's public transportation ticketing system is organized. This analysis is included in this chapter, along with the main challenges of using BLE Beacons in this specific context.

## 3.1 Intermodal public transportation network

In Porto, the public transportation system includes several different platforms: bus, light rail and train. To unify this intermodal system, a ticketing platform was created, *Andante*. The *Andante* system implements the use of RFID smartcards with two different ticketing options: either as a rechargeable card, that can be topped up with tickets; or as a subscription type plan, with a fixed monthly cost. *Andante* can be used across all different platforms and companies that participate in the program.

The geographic area of action of *Andante* is organized by a set of zones. Each of the zones has a code, and the titles that the users can buy limit the zones the user can travel. For each trip, the user must have a ticket valid for the number of *rings of zones* that will be travelled. Tickets range from a radius of two zones (Z2) to twelve zones (Z12). For a better understanding of this concept of *rings of zones*, in Figure 3.1 is an example of the ticket type needed for a trip starting in zone C6. The tickets not only limit the zones that the user can travel, but also establish a period of time during which they are valid, after validation. These periods of time range from two hours, for the minimum fare (Z2), all the way to three hours and fifteen minutes, in the maximum fare (Z12).

For the individual title smartcards, Andante imposes a limit of only one type of title per smartcard, meaning that the user can't have, for example, Z2 and Z3 titles simultaneously in the same card.

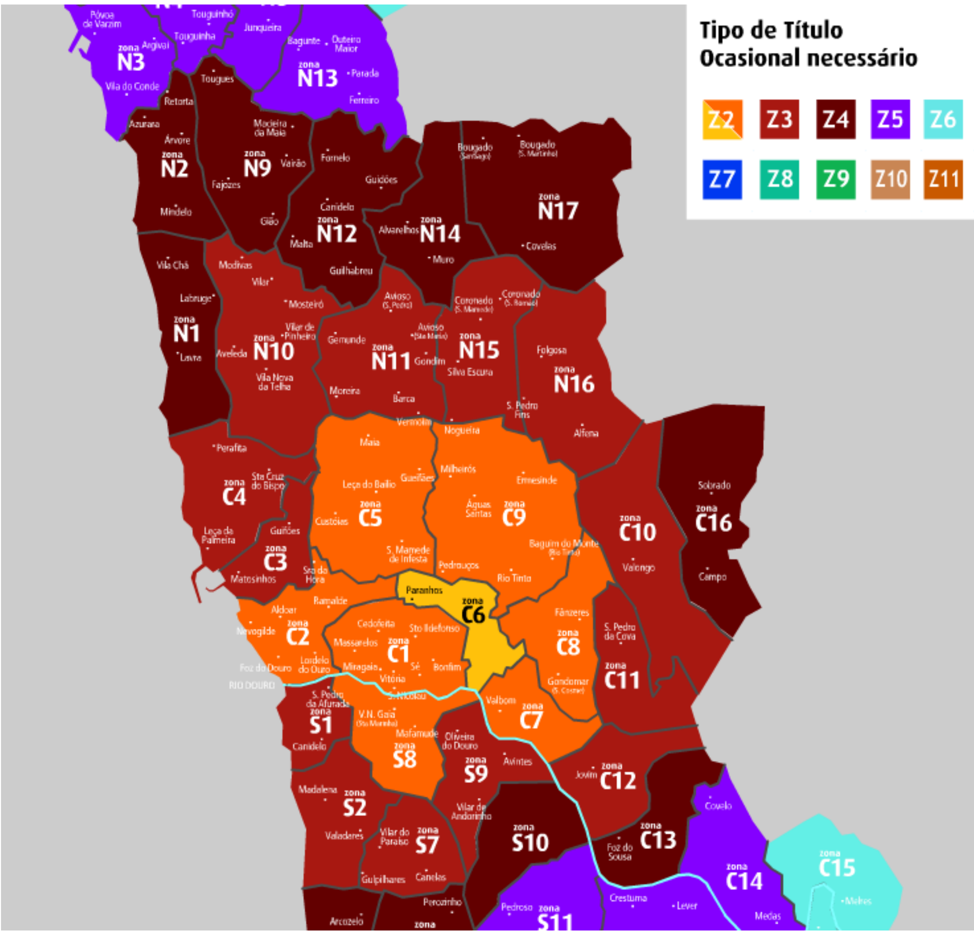


Figure 3.1: Porto's Zones and Ticket types [Trad]

The main difference between the individual titles and the subscription based approaches is that in the first, the user can travel in any zone within the radius of zones established by its ticket, while in the latter, although the pricing is also based on the concept of *rings of zones*, the user can only travel in a specific set of zones, pre-established when the user starts the subscription plan. In spite of this limitation, a subscription plan is usually beneficial for frequent travellers, as it allows for unlimited trips.

While the light rail system implemented in Porto requires the use of *Andante* cards, both bus and train networks, in addition to the use of *Andante*, allow users to buy individual tickets, directly from the driver, and in ticket offices, respectively.

## 3.2 Open gated system

### 3.2.1 Basic features

Light rail transportation usually uses a gated approach to control users' access to the stations. This means that the user must validate its ticket at the gates, in order to gain access to the boarding areas. Good examples of this approach are London's and Barcelona's light rail systems.

Porto's approach is an open gated platform, in which there are no physical gates through which users must walk. This type of system allows the existence of open air stations without any type of barriers. Although this system allows the users to have an easier and less constrained access to the stations, it still makes the users responsible for validating their *Andante* tickets before initiating a trip.

The train network works in a similar fashion to the light rail in Porto. The bus network, although by nature can't quite operate in the same way, uses the same type of validators inside each vehicle, creating a seamless integration among all the different transports.

### 3.2.2 Advantages and limitations

The main advantages of an open gated system are that it allows users to move more freely, minimizes people congestion at the validators in stations, and provides a greater versatility on the stations' layout and design because it doesn't require the existence of a closed space with controlled access. Besides all these advantages, this approach also requires less financial investment from the operators by simplifying the ticket validation hardware and minimizing the complexity of the physical infrastructure of the stations.

Despite having many advantages, an open gated system also has its downsides. Not having any physical access control (open gated system) means that when a trip ends, the user will simply leave the vehicle, no further ticket validation needed. This makes it impossible for operators to have any information on where the users end their trips, only where they start. Although this information is not needed in a strictly functional point of view, it could be beneficial for a more efficient management of resources, such as a more adequate allocation of vehicles for certain zones, or by simply allowing for a greater confidence on what infrastructures should receive more investment according to their usage.

Another area where the *Andante* platform is limited is that it always requires the existence of a physical card. In the last few years, many companies, such as airlines or event organizers, started to create ways to avoid the need of physical tickets by taking advantage of the fact that most of their customers have smartphones. The use of smartphones allows the migration of the tickets from a strictly physical existence, to a digital form. To use this tickets, and as explored in chapter 2, different technologies can be used, such as NFC or Bluetooth, or even the simpler QR Codes.

Currently there is no way of buying *Andante* tickets online, nor in any digital form. These purchases must be made at ticket machines at the stations, official *Andante* offices, or authorized ticket sellers. The use case that would benefit more from a more versatile purchase option, would be the individual title purchase. The main problem in implementing an alternative to the current system, is that the travel titles are stored in the users' *Andante* cards, they're not virtualized in any way, so any improvement suggested will almost certainly imply changes to the current system, mainly on the concept of ticket, and how it is represented.

Despite the challenges that such changes could imply to a major public transportation network such as Porto's, some benefit would also come from it. By redirecting some of the traffic of ticket purchases from physical selling points to an online platform, operating in each user's smartphone, would reduce the stress over the whole ticket purchase physical infrastructure, the queues at ticket selling points would be less frequent, and the financial cost of purchase and maintenance of hardware would be also be reduced. The fact that tickets could be bought at any time, in any place, would be the most evident benefit to users, that wouldn't depend on the availability of ticket offices or machines to travel.

## 3.3 Trip process

The trip process with *Andante* initiates with the user validating the ticket by approaching the smartcard to the validation terminals. After the validation, the user can travel within the zone limit of the ticket. The user can also make multiple trips within this limit, and use only one ticket, but has to make sure that the last validation is made before the end of the time limit of the ticket. The only interactions the users have with the system are this initial validation, and any possible inspections

The complexity of the ticketing system implemented in Porto makes it difficult to handle not only for occasional or new and one-time users, which have to learn how it works, but also for frequent users, which have to keep track of the zones they want to travel, and own multiple smartcards for different tickets.

## 3.4 Inspection

Due to the nature of an open gated public transportation system, there is no physical way of enforcing users to validate their tickets and ensuring everyone is travelling legally. To ensure that everyone validates their tickets, and discourage fraud, inspectors often get in vehicles and validate the users' tickets, checking whether they are valid or not, and if not, a fine is issued to the passenger. These inspections mostly succeed in forcing users to travel with a valid title because they are always unannounced, and completely random to the eyes of the travellers.

# Chapter 4

# Anda: a mobile ticketing solution for public transportation in Porto

## 4.1 BLE Beacons in public transportation

Although the market is already filled with many mobile ticketing solutions that use most of the technologies available today, the use of BLE Beacons as part of it is mostly unexplored, and even less in the context of public transportation. Unlike technologies such as NFC, which isn't available in several smartphone models, even the most recent ones, Bluetooth is a technology widely available since the launch of the first smartphones, thus making its use of great potential.

Anda is a mobile ticketing solution designed and developed as part of a pilot test, integrated with the *Andante* platform in Porto, and that takes advantage of the use of BLE Beacons. The main goal of Anda is to be a platform that is seamlessly integrated with Porto's intermodal public transportation network, while simultaneously bringing to the users a pleasant experience, either by its simplicity of use, or by the many advantages that a service like this can offer.

The core element of the Anda platform is a mobile application that is installed in the users' smartphones, and that will be the only interface that users use to interact with the system. To provide the simplest experience possible to the user, Anda was developed in a way that reduces the user input to the minimum. This is achieved by using BLE Beacons which allow the tracking of the users' trips from beginning to end. There are two possible implementations of this tracking, either by installing BLE Beacons on the vehicles, allowing the application to detect them during the whole trip, and automatically ending the trip when it stops receiving a signal from them, or by installing the beacons at the stations/stops, and detecting the trip by registering the sequence of detected beacons along the journey.

Installing the beacons on the vehicles provides a much less error prone solution, because while on trip, the mobile application only needs to keep checking if the beacon signal is still being received, and if not, it means that the user has exited the vehicle, ending the trip there. Along the course of the trip, the beacon changes the information it broadcasts, allowing the application to know the current stage of the trip, making this implementation more complex regarding the

BLE beacons technology. There may be unwanted detections along the trip, such as signals from beacons installed in other vehicles nearby, but the handling of these detections is not a problem, because they can be immediately ignored. The second approach, consisting of installing the beacons on stations/stops, also presents a valid proposal, but comes at some cost. In this case, the mobile application has to inspect all detections, and select the ones that make sense in the current context of the trip, for example, if the user is on a light rail trip, any detection relative to a bus line would be irrelevant. To end the trip, if following this approach, the application would have to, after a predefined period of time, if no new detections were registered, end the trip at the last stop whose beacon was detected. This approach represents a much more complex trip process for the mobile application, but a simpler implementation regarding the programming of the BLE beacons, because their signal would never change (each beacon always broadcasts information about the stop it is installed at). Although there is the challenge of programming the beacons to change the broadcasted information during the trip, the on-vehicle approach is preferable because it provides a simpler and more effective way of tracking the trip from its start point, all the way to the end.

The implementation of *Anda* uses both beacon installation approaches described above. On the bus fleet, the on-vehicle installation was used, and for the light rail and train network, the beacons were installed at the stations. After analyzing different possibilities, it was decided that the beacons would be installed inside the ticket validators that are present in every light rail and train station. Although the preferred approach would be to have beacons installed in every vehicle, it wasn't possible due to restrictions regarding the light-rail vehicles and trains.

The main innovation in Anda is that with its BLE beacon network, it becomes possible for the whole trip to be detected, and recorded. This feature is mostly important for a public transportation network such as Porto's, which is, simultaneously, open-gated and billed by trip length. This BLE beacons implementation not only has the potential to succeed in this task, as it has the possibility of doing that by requiring minimal input from the user.

## 4.2 Post-billing and tariff optimization

As described before, a BLE beacon based platform such as Anda has the versatility to be implemented in a complex intermodal public transportation. By tracking the trips from their start point to the end it becomes able to handle with the complex zone based ticket system of *Andante*, and creates new possibilities regarding the fare collection.

The Anda proposal suggests that, opposed to *Andante*, the platform implements a post-billing system, in which the users' trips are only charged by the end of the month, after the fact. In addition to the post-billing, Anda proposes that a tariff optimization is offered to the user. This optimization consists on charging the user the minimum value possible for the trips made during the month, by combining these trips in a set of *Andante* monthly subscriptions and/or individual titles, resulting in minimal price. To better understand the tariff optimization, below is illustrated an example scenario.

**Tariff Optimization Example**

This example features a user that on a specific month made daily commutes using the light rail line, which consist on trips between zones C1 and C2, and also made 8 extra trips to zone C6.

- **Current approach** - User buys a monthly subscription for zones C1 and C2 (Z2, for 30.10€), and 8 individual Z2 titles (9.60€), paying a total of 39.70€.

- **Anda's approach** - User makes all his trips using Anda, and at the end of the month is billed for a Z3 subscription (zones C1, C2 and C6), for 36.00€.

This concept is totally different from the current approaches, because it suggest a total dematerialization of the ticket. Until the end of the billing cycle, there are no tickets, there are only records of the users' trips. The main advantage of a platform like this lays on the fact that the user no longer has to plan in advance, and acquire tickets or buy a monthly subscription before using public transportation. Users can simply make their trips, always using Anda, knowing that, by the end of the month, they will be billed by the best tariff possible.

Tariff optimization, when combined with the minimal interaction between the platform and the user provided by Anda, helps to make the whole public transportation system almost an abstraction to the user. None of the complexity of the system is visible, leading to a more pleasing experience when using the public transportation network, not only for first-time and occasional users, but also for frequent travellers. All these advantages of Anda have their importance amplified in a public transportation system such as Porto's, which is more complex than most, as described in Chapter 3.

## 4.3 System architecture

To better understand the general architecture of Anda, Figure 4.1 shows all the different components of the platform, as well as how they interact with each other.

Anda's architecture can be analyzed be dividing it in three different levels: the mobile application, the BLE beacons, and the back-end. Below is an overview of each of these levels.

The back-end works as the base of the platform, and is where all the information regarding the users and their trips is stored. Anda's back-end receives information from the mobile application regarding the trips that users make. This information is processed and prepared to be sent to the central ticketing service, and also the tariff optimization algorithm is used to update the current best tariff for the user. The back-end is also responsible for data analytics and is the source for trip history and paid fares which are shown in the application.

Regarding the mobile application, for the pilot test it was developed for Android devices only. In order to be able to detect the BLE beacons, a dedicated library is used. This library was developed specifically for this platform, and allows for an abstraction of the whole beacon detection process by acting as a detection listener which only notifies the application at key moments, such as when a new station is detected, or an error occurs.

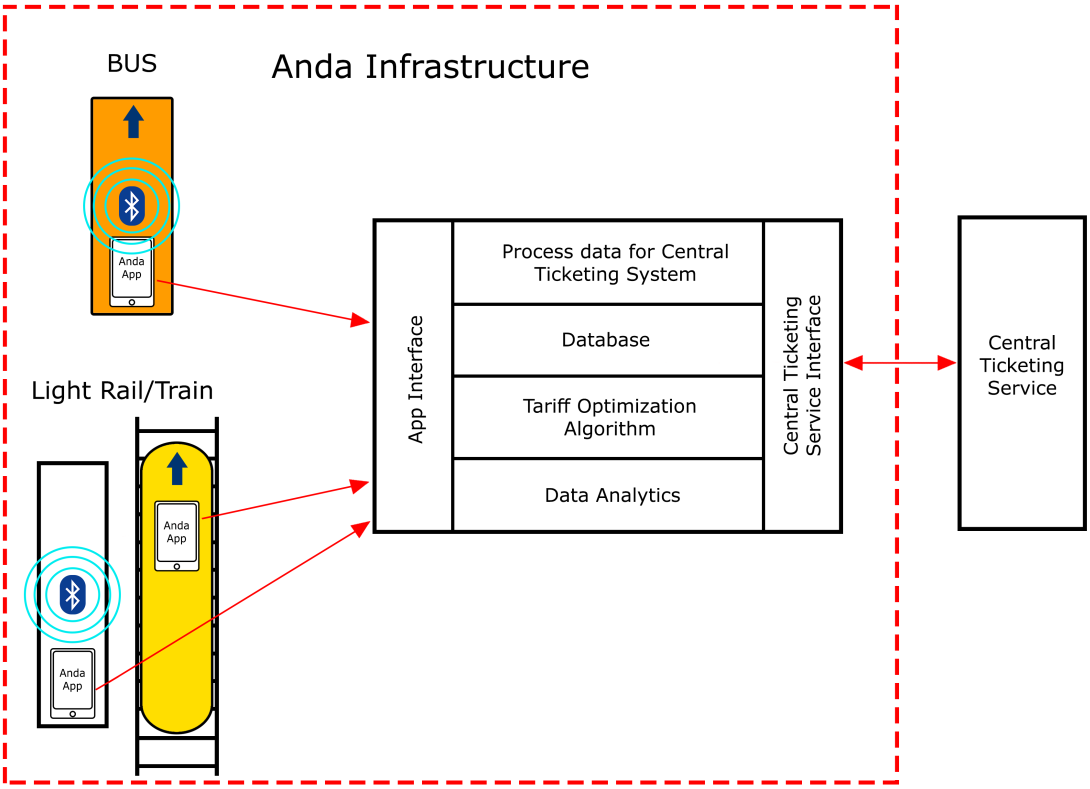


Figure 4.1: Anda architecture

The BLE beacons were deployed with two different approaches. The first approach, the most simple, was used for beacons that are installed in light rail and train stations, meaning that their position is fixed. These beacons are programmed to always broadcast the same signal, relative to the station they're installed at. The second approach, used for beacons installed in buses, is more complex. These beacons, in order to be able to change the information that is sent to the users, have to be connected to the onboard computer of the bus, to get the stops information from it. To make this connection, two alternatives were considered:

- **Connect via cable** - this solution suggests a direct connection between the beacon and the onboard computer with a cable. This doesn't require any software or hardware changes in the computer, is compatible with every public transportation operator, doesn't require any extra hardware, and assures that the connection would be permanent. The downsides of this approach are the limitations that it may impose regarding the location where the beacons can be installed, and a potential signal loss with longer cables.

- **Connect via BLE dongle** - this second alternative suggests the use of a BLE dongle (RS485-BLE, RS232-BLE or USB-BLE). The use of an RS485 or RS232 dongle would require hardware changes because the onboard equipments don't have these ports, and the USB dongles aren't robust enough, and every alternative would require software changes. Another downside is the fact that these dongles require an extra power source. The main advantage of this solution would be the lower limitations to the beacon location inside the vehicle.

After analyzing the up and downsides of each of these solutions, the connection with cable was chosen because of its extra robustness and reliability.

## 4.4 Mobile application

The mobile application is the central element of the whole Anda platform. This application will be the only interface between the users and the public transportation system, and the element that facilitates the existence of a seamless experience of Anda. To go along with this ease of use intended for Anda, the application has a simple interface, and aims to be as intuitive as possible.

As a starting point, the user is presented with a *landing* screen (Fig. A.1) where it is possible to navigate to either the login or the registration screens, whether the user is already registered or not. The login screen (Fig. A.3) simply asks users to enter their email and password, while the registration screen (Fig. A.2) the users are prompted for their personal details, contact information and password.

After signing in, the application's main screen becomes the one where the current trip possibilities are listed. Each item listed matches one or multiple beacons that are being detected for a specific nearby location. Users start their trip process on this screen by selecting the current stop they're in, and confirming the start of the trip (Fig. A.4). After this step, no further interaction with the application is needed from the user, the application will be in charge of tracking beacons during the trip, either the on-vehicle beacons (for bus trips) or the sequence of stop beacons (for light rail and train trips). During the trip, users can still use the application, and the sequence of detected stations is displayed on the trip screen (Fig. A.5).

When users are travelling by bus, the application only has to keep tracking the vehicle's beacons. As long as these beacons can be detected, the trip is still ongoing. Once the application stops detecting any of the vehicle's beacons, it means that the user has exited the bus, and the trip has ended. The users' route is obtained by constantly reading the information broadcasted by the beacons, which include the stops by which the bus is passing.

For light rail and train trips, as explained before, the process is more complex. In this case, the application has to keep scanning for new beacons, which are installed only in the stations. The route is detected by assembling the sequence of beacons detections and the trip ends when a certain pre-defined timeout period expires. If no beacon is detected during this period, it means that the user ended the trip on the last station whose beacon was detected.

The inspection with Anda would work in a similar fashion of the current solution, so there is also an inspection screen (Fig. A.6). On this screen an alphanumeric code is displayed, and inspectors can use this code to verify if the user has a valid trip on Anda.

At last, there are two screens related with the users' trip history. The first one, the history screen (Fig. A.7), shows only a list of the trips made by the user, showing the start and end points for each one, along with the correspondent operator. On the second screen, the fares screen (Fig. A.8), users can consult the result of the tariff optimization on their trips. By default, both of these screens show information of the current month, but any month can be consulted by selecting it on the top bar.

## 4.5 Challenges

Although the use of BLE beacons in a mobile payment system for public transportation brings many advantages to all the parties involved, its implementation may face several challenges along the way. One of the key challenges that the platform may face is the viability of the technology. BLE beacons still aren't widely used, and there isn't any feedback about an implementation on the same terms as Anda.

The main concerns regarding the viability of the use of BLE beacons are whether the technology can be relied on to track users' trips effectively or not. Being Bluetooth devices, BLE beacons work on the same frequency as every other Bluetooth device, as well as most Wi-Fi networks which also work at 2.4GHz. With almost everyone carrying a smartphone on their pocket, there is a huge amount of devices that will potentially create interference with the beacons signal, reducing the chances of effectiveness of the use of BLE beacons. One of the main challenges of this platform is then, to get a reasonable relation between the number of BLE beacons installed at each location and its effectiveness. This is the most critic aspect of the whole platform, because if it can't achieve what it purposes to, which is the tracking of users' trips from start to end, something that is necessary in a public transportation network such as Porto's, its implementation won't be viable.

Another important aspect that can affect Anda's success is user acceptance. Although Anda brings many advantages over traditional ticketing solutions, the technology used is fairly recent, and not well known by the general public, making the acceptance of the whole platform a potential problem. The seamless experience that is achieved with the use of Anda may be enough to overcome this risk, but this aspect can only be assessed after real users start to use the platform and give their feedback, which was one of the goals of the pilot test conducted.

# Chapter 5

# Monitoring BLE Beacons

## 5.1 Deployed Beacons monitoring

Besides the analysis of user acceptance, and general viability of the project as a whole, it becomes interesting to examine the behaviour of BLE beacons when deployed to their final location, where they may be subject to infrastructural restrictions, or signal interference from nearby devices.

To make this analysis, a platform for monitoring the deployed beacons was developed. The main goal of this platform is to use the smartphones to record beacon detection data near the deployed Anda BLE beacons, to be analyzed later.

In order to register beacon detections, the mobile application uses a dedicated library, developed by the same team that developed the beacon detection library for the regular Anda application.

The main goal of this platform is to allow the evaluation of the performance of BLE beacons, by analyzing the collected data and comparing it to the expected values, and to help to troubleshoot problems reported by the users of Anda.

## 5.2 Architecture

The developed platform has two main components: a mobile application and a back office. The mobile application's goal is to help collecting beacon data, while the back office is a centralized hub where the collected data can be analyzed.

As for the mobile application, and in order to maintain the consistency relatively to the Anda application, it was developed for Android, using the Android native development environment. This application, as stated before, uses an external library for beacon detection, based on the beacon detection library used on Anda's mobile application. This external library was chosen in favour of native Android beacon detection methods because the beacons used in this project use proprietary technology, and only by using a dedicated library would become possible to obtain information of the line, stop and operator of the detected beacons, and also for the sake of consistency with the methodology used for beacon detection in Anda.

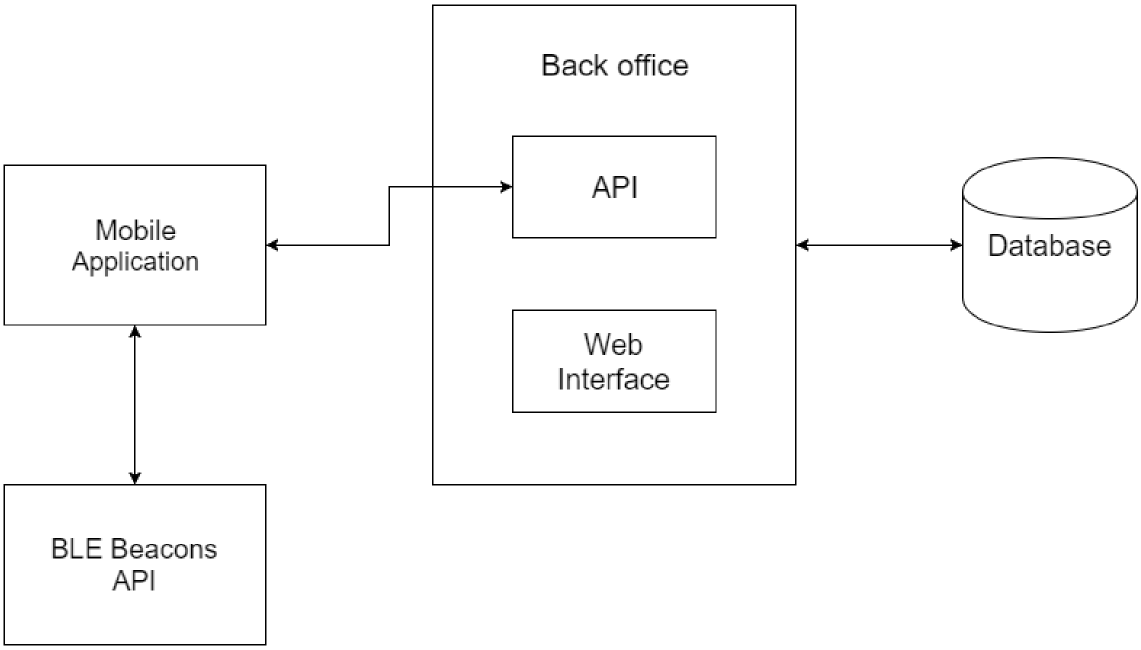


Figure 5.1: Beacon Monitoring platform architecture

The back office works both, as a bridge between the mobile application and the database, and as a tool to visualize the collected data. The first part, the connection between the smartphone application and the database, is made via an API that has some simple services to bridge both components. The data visualizer is essentially a web interface to browse all the collected data in the database, by connecting directly to it.

The database stores user information, which allows the existence of an authentication mechanism, and the beacon detections data along with possible errors returned by the beacon detection library. The database schema is represented in Fig. 5.2.

The interaction among the different components that compose this platform is represented in Fig. 5.1.

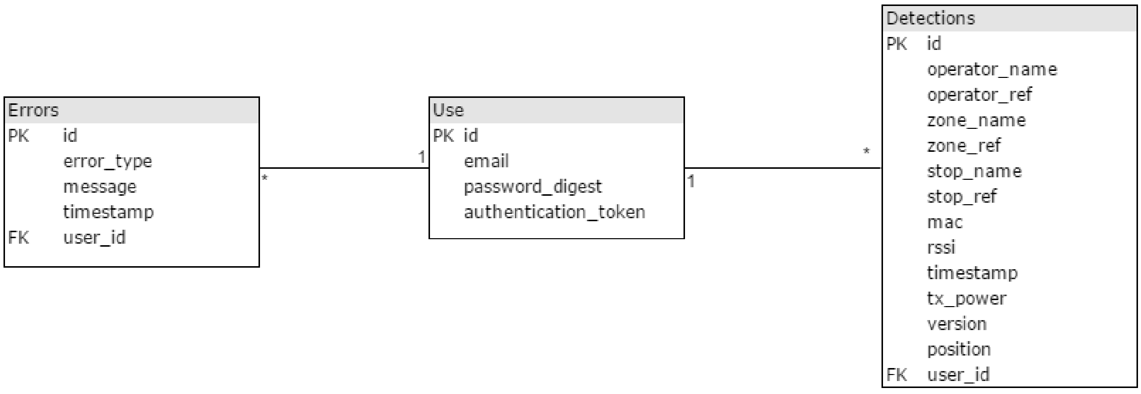


Figure 5.2: Database schema

### 5.2.1 Technologies

For the mobile application, an Android native environment was used, using Java as the programming language, and Google's Android SDK [Gooa], in order to maintain the consistency with Anda application, which was also developed with similar technology.

To process the beacon detections in the application, as stated before, an external library was used. This library provides a listener that notifies the application each time there is a beacon detection or an error. For both cases, an object is returned, containing information about either the detection or the error.

To communicate with the back office API, another external library was used: *Android Asynchronous Http Client*, by James Smith [Jam]. This library simplifies the process of making HTTP requests in Android, while being very light and easy to use.

For the backend, *Ruby on Rails* was used. *Ruby on Rails* (or simply *Rails*) is a web application framework that establishes a set of conventions that facilitate the process of development and maintenance of a web application. Rails uses an MVC approach, and is frequently used to develop *data-oriented* applications, and provides easy to use mechanisms of generating web services. As another benefit, *Rails* also strictly links the web application's data schema to the database, and makes this connection as simple as defining the database host and credentials on the application.

A *PostgreSQL* database was used to store all the data. *PostgreSQL* is an object-relational database, and was chosen by its versatility, extensive number of features, and also by previous experience with the technology.

Both, the web application and the database were hosted in a free *Heroku* account. *Heroku* is a cloud based hosting service that allows the deployment of web applications developed in several different environments, including *Ruby on Rails*, as well as the hosting of *PostgreSQL* databases. One of the main advantages of *Heroku* is its integration with *GitHub* (a version control platform for software code) which allows automatic deployment of the application once its pushed to a specific branch of the application's repository.

## 5.3 Smartphone Application

The mobile application developed to monitor beacons was developed with a simplistic interface, with only few screens, in order to make the work on the field as easy as possible. The only actions possible in the application are monitoring start and stop, user sign in, and data upload.

The main screen of the application is where the monitoring can be started and stopped, and where the recorded detections are listed, along with the errors returned by the detection library. Both, detections and errors, are displayed in a list of cards with core information, in two different tabs.

The main screen of the application is displayed on Fig. 5.3. The screen displays a list of all the beacon detections recorded on the first tab, and a list of errors on the second tab (on the right). On the detections tab, each card displays the public transportation operator of the vehicle/station where the beacon is installed, the MAC address of the beacon, and the RSSI of the detection. For each error, the error type and message are displayed.


Figure 5.3: Beacon monitoring screen

There is a menu on the top right corner, where the monitoring can be started and stopped (Fig. 5.4).

Besides listing all the new detections on the main screen, while the beacon monitoring is active, there is also a persistent notification, indicating that the application is listening for beacon broadcasts, and how many detections have been recorded so far.

The upload of the recorded data to the server is made by accessing a second screen, accessible by a side menu (Fig. 5.5). The data management screen Fig. (5.6) only displays the number of detections and errors stored on the local database, and allows each of the sets to be uploaded to the server.

In order to perform the upload, the user must be logged in (Fig. 5.7). The login functionality is also accessible in the side menu.

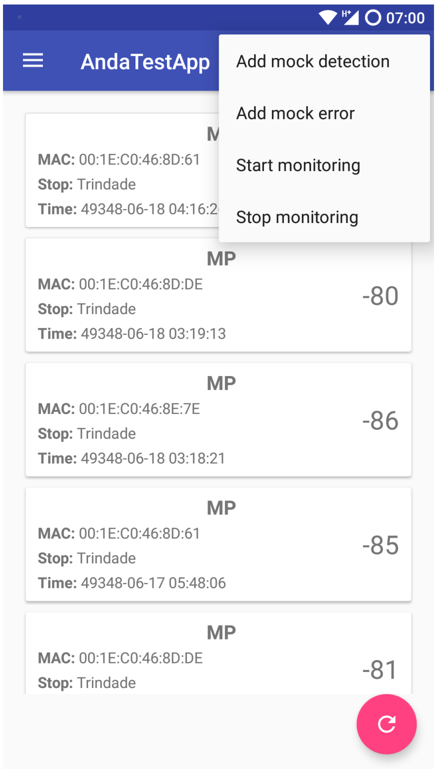


Figure 5.4: Top menu

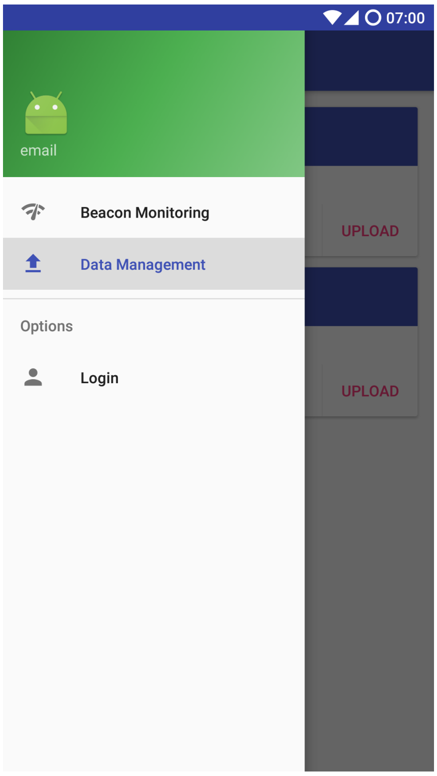


Figure 5.5: Side Menu

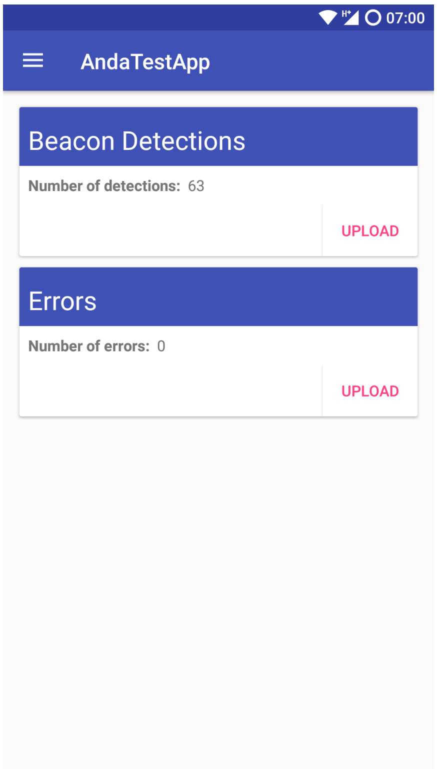


Figure 5.6: Data management screen

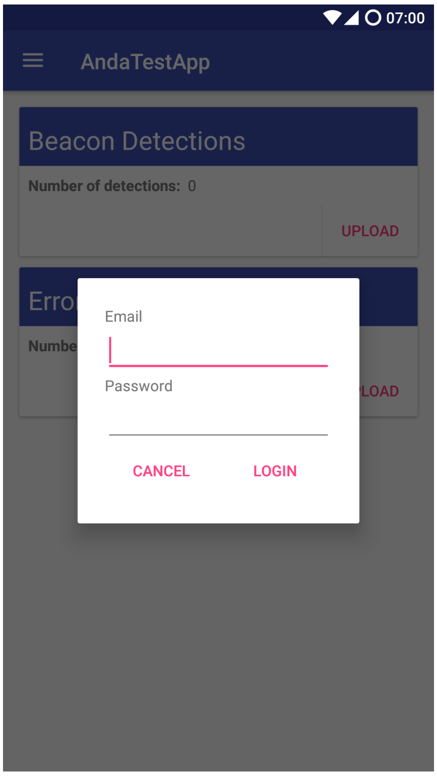


Figure 5.7: Login modal window

## 5.4 Back-end

The back-end has two main components: the API that's used by the mobile application, and the web application where the data can be consulted.

### 5.4.1 API

The API allows the mobile application to communicate with the back-end, and provides the necessary web services for authentication and data transfer:

- **Login** - POST /sessions - This web service receives a JSON object with user information and returns an authentication token and the user ID. Below are examples of the data sent and received.

  **Request content:**

```
{
    user:
    {
        "email": "example@example.com",
        "password": "012345"
    }
}
```

  **Response content:**

```
{
    "id": 15,
    "email": "example@example.com",
    "authentication_token": "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX"
}
```

- **Upload Detections** - POST /insert_detections - This web service receives a JSON object with detections objects. For each detection all the details got from the beacon detection library must be sent, along with the ID of the detection at the local database on the smartphone. By sending the local ID, it becomes possible to report which specific detections were uploaded successfully and which weren't. Below are examples of requests and responses. This API service requires user authentication, which is done with the help of an authentication header (*Authorization*) which contains the user's email and authentication token.

  **Request content:**

```
{
    detections:
```

```
    [
        {
            "local_id": 50,
            "operator_name": "MP",
            "operator_ref": 2,
            "zone_name": "C6",
            "zone_ref": 6,
            "stop_name": "H. Sao Joao",
            "stop_ref": 47,
            "mac": "00:D2:CC:52:70:E9",
            "rssi": -78,
            "timestamp": 1492529858290,
            "tx_power": 52,
            "version": 1,
            "position": 1
        },
        ...
    ]
}
```


**Response content:**

This example represents a response to a successful request. The request was correctly parsed, and the detections may have been inserted or not. The local IDs of the inserted detections are sent in the response.

```
HTTP Status Code: 201
{
    status: "Ok",
    inserted_ids: [50, 51, 52, ..., 59, 60]
}
```

When there is some server-side problem, none of the detections is inserted, and a HTTP 406 response code is sent.

```
HTTP Status Code: 406
{
    status: 'No detections inserted'
}
```

### 5.4.2 Web application

Besides the API, the other big part of the back end is a web application. The main goal of this web application is to allow to analyze the data collected with the smartphones. This web application was developed as a simple way to consult data, by permitting the search for a specific beacon, operator or stop, and displaying graphs which allow a quick and easy interpretation of the collected data.

There is a registration page (Fig. 5.8) in which the user only has to enter an email address (which becomes his unique identifier), a password and its confirmation. This registration details are the same that shall be used on the mobile application, which means that the user will only be able to upload data via the mobile application after registering in the web application. Although there won't be several users using this platform, an authentication mechanism was necessary to prevent unauthorized interactions with the API and web application.

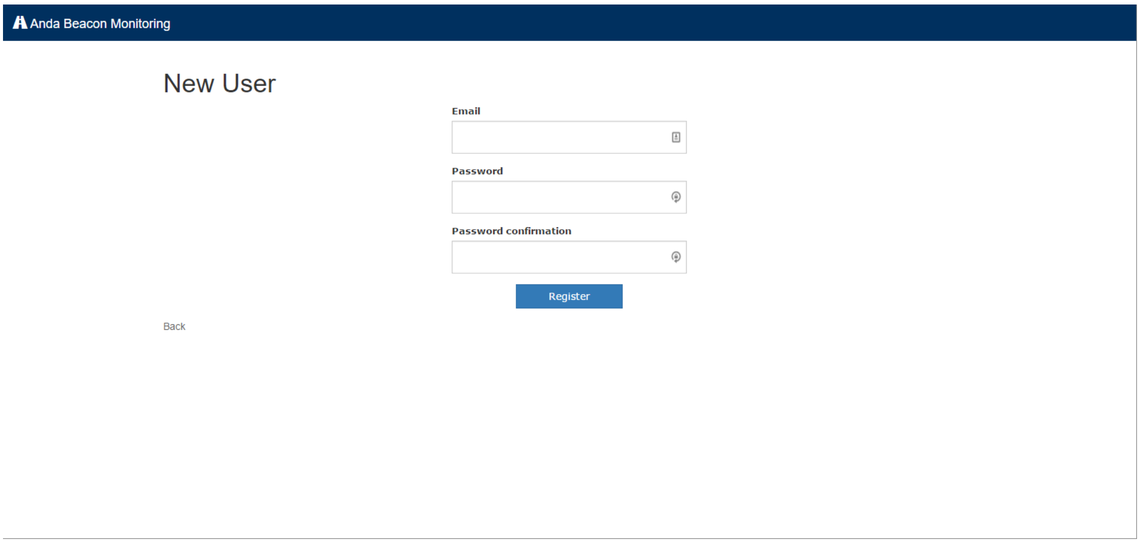


Figure 5.8: Sign up

In addition to the registration page, there is also a login page (Fig. 5.9) where the user can sign in with its details.

The main page of the web application is an index of all the detections collected (Fig. 5.10). In this index, it is possible to filter detections by searching keywords in specific fields, such as beacon MAC address, line, stop and operator. This feature allows to limit the data to specific detections, and possibly allowing for more insightful conclusions about the collected data.

One of the main features of the platform is the possibility to plot graphs based on detection data. By selecting a specific MAC address on the index page, the application redirects to another page which shows a graph which displays the detections of the selected beacon, plotted according to their timestamp and RSSI (Fig. 5.11). This page also allows the user to filter the detections by date and time, allowing for a more specific analysis of the results.

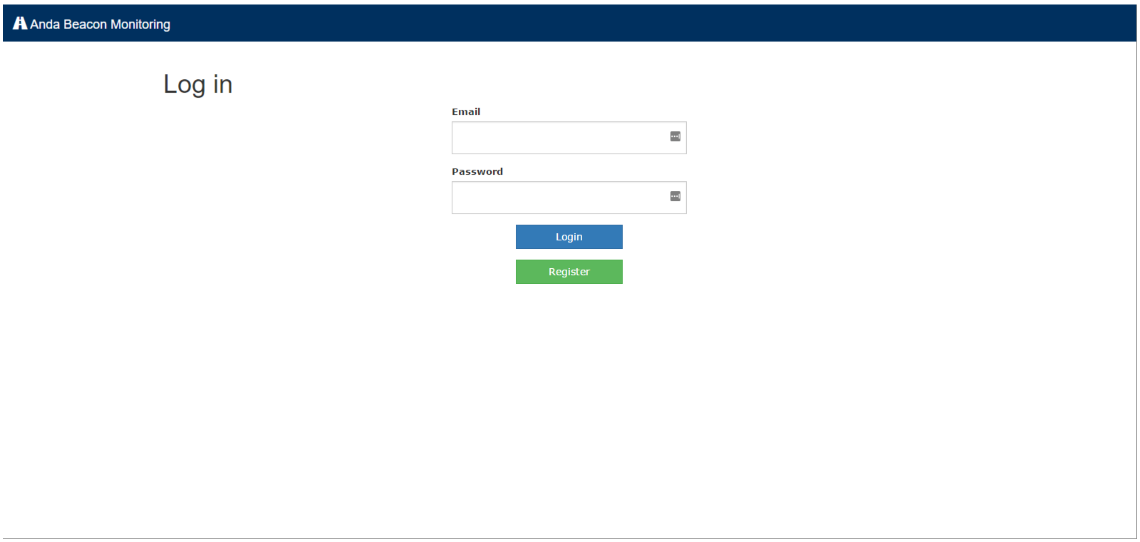


Figure 5.9: Login

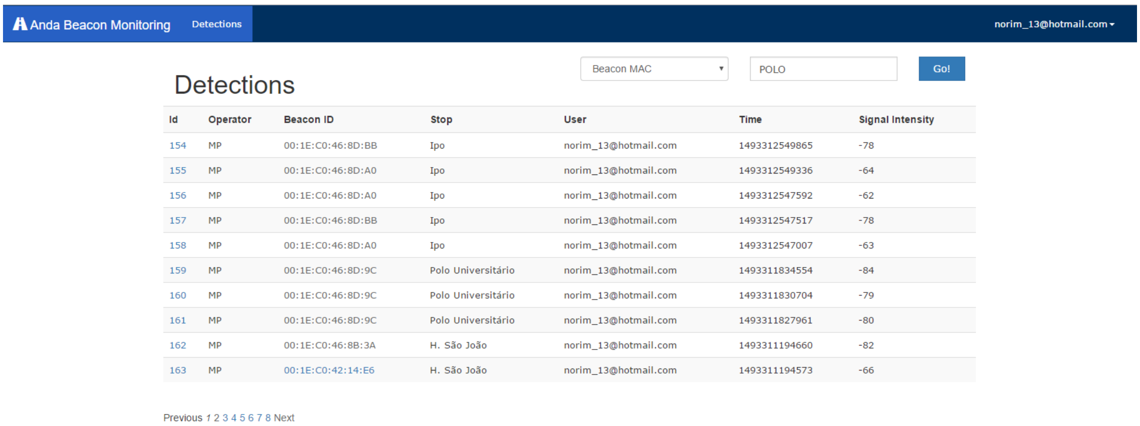


Figure 5.10: Detections List

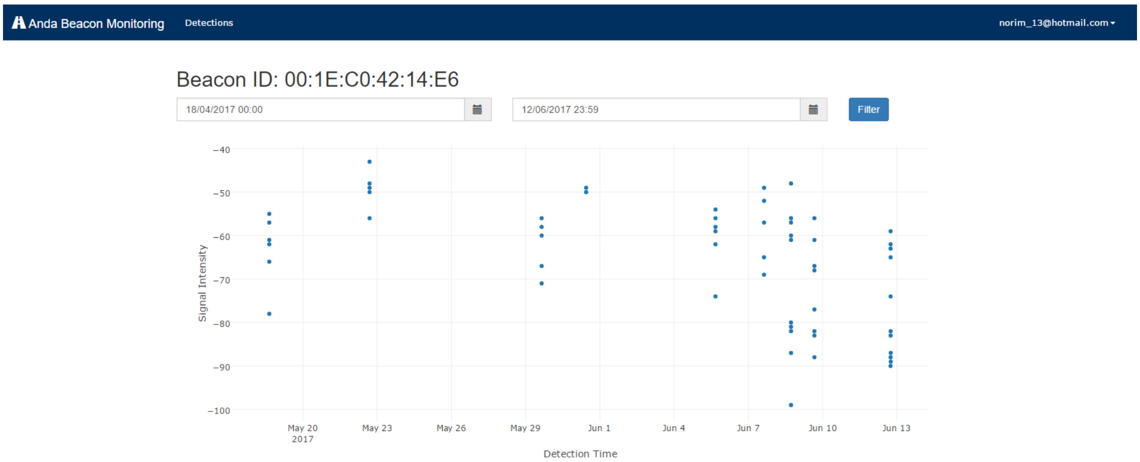


Figure 5.11: Detections by beacon

# Chapter 6

# Results

## 6.1 Beacon Monitoring

In order to assess the viability of the whole proposal of a mobile ticketing solution using BLE beacons, one of the key aspects that needed to be evaluated was the performance of the beacons when deployed on their final locations.

### 6.1.1 Methodology

To make the beacon monitoring results relevant for the evaluation of the platform, the methodology used for it was thought with focus on the consistency of the readings.

For both, train and light rail beacons, which are installed in fixed locations, a set of beacons was chosen, and several readings were registered for each of them, on several different occasions. For beacons installed on buses, as it's very difficult to ensure that the readings are made in the exact same bus, because several buses are on the same line simultaneously, the monitoring was made by recording data from random vehicles.

The first set of readings are relative to the light rail and train implementations of the platform. The main goal of this first approach is to simulate a scenario where users enter underground stations, in which there are validators at each entrance, and at least one beacon installed in one of those. Having these conditions in mind, during the readings, the smartphone was kept within a range of 2 to 2.5 meters from the beacons. This range was chosen because users will most likely always have to pass within this range from at least one beacon while entering or exiting the station.

Although these close range readings of the first set would be enough for underground stations, on street level stations where there are validators usually at two opposite corners of the central area of the station, they wouldn't reflect all the possible use case scenarios of these stations. Because the vehicles are very long, there may be some problems when users enter or exit the vehicles by the doors on each end of them, where the signal from the beacons will be weaker, and may not be detected. The second set of readings aims to test these extreme use cases, by measuring the received RSSI at the very end of the vehicles while they're stopped at the stations.

The third set of readings concern beacons installed on buses. During these tests, data was collected from different areas of the bus, namely, the front and back rows on the bottom floor, and on the top floor. This areas are enough to have a general idea of the performance of the BLE beacons inside the vehicle by covering every extreme use case scenario.

The readings were made during several different days, and for each day, four to six readings were registered by beacon. Not every beacon was monitored on every day of testing, so the number of readings for each beacon may vary.

All the readings were made using the developed beacon monitoring application, described on Chapter 5, installed in a device with version 7.1.1 of Android.

As the light-rail and train networks use the same implementation of platform, the monitoring data only concerns beacons installed on light-rails validators, either for close range and long range readings.

### 6.1.2 Close range light-rail readings

Close range readings were made at both, underground and street-level stations. Not every station's beacons were monitored, because most of them have similar validator layouts, so some stations with different layouts were chosen to collect data at. The selected stations are listed on Table 6.1 along with the position of the beacons that were monitored at each of them. The positions referred on the table can be matched to their location by using the station layouts in Appendix B.

Table 6.1: Beacon postitions for close range readings

| **Station** | **Beacon positions** |
|---|---|
| Hospital S. João | 1, 2 |
| IPO | 1, 2 |
| Faria Guimarães | 1, 2, 3 |
| Trindade | 3, 4, 5, 7, 8 |
| S. Bento | 1, 2, 3, 4 |
| Jardim do Morro | 1, 2 |
| Santo Ovídio | 1, 2, 4, 5, 6, 7, 8 |

The results of the readings were summarized and the most relevant resulting data is displayed in Table 6.2. To give an idea of the fluctuation of the readings, the table includes not only average RSSI values for each position, but also its standard deviation, as well as minimum and maximum readings.

After analyzing the results, it is possible to conclude that almost every beacon performed well, with RSSI averaging around -60dB. The minimum RSSI values can also be interpreted as positive, because they represent the worst cases regarding the performance of the beacons, and none of these values is below -88dB.

Table 6.2: Close range readings results

| **Station** | **Position** | **Maximum**(dB) | **Minimum**(dB) | **Average**(dB) | **Std. Dev.**(dB) |
|---|---|---|---|---|---|
| H. São João | 1 | -43 | -78 | -58.09 | 7.36 |
| H. São João | 2 | -52 | -83 | -61.38 | 7.71 |
| Ipo | 1 | -45 | -82 | -57.21 | 9.79 |
| Ipo | 2 | -57 | -78 | -62.67 | 5.02 |
| Faria Guimarães | 1 | -52 | -82 | -60.38 | 6.37 |
| Faria Guimarães | 2 | -53 | -76 | -59.80 | 6.30 |
| Faria Guimarães | 3 | -58 | -85 | -66.18 | 6.37 |
| Trindade | 3 | -65 | -88 | -77.10 | 5.88 |
| Trindade | 4 | -65 | -88 | -75.67 | 7.97 |
| Trindade | 7 | -50 | -75 | -61.07 | 5.55 |
| Trindade | 8 | -50 | -83 | -63.56 | 9.22 |
| São Bento | 1 | -46 | -76 | -60.55 | 7.76 |
| São Bento | 2 | -54 | -81 | -62.67 | 7.14 |
| São Bento | 3 | -49 | -76 | -58.47 | 5.28 |
| São Bento | 4 | -54 | -83 | -65.12 | 6.37 |
| Jardim Do Morro | 1 | -52 | -83 | -63.65 | 6.20 |
| Jardim Do Morro | 2 | -50 | -75 | -61.23 | 7.59 |
| Santo Ovídio | 1 | -61 | -84 | -67.82 | 7.07 |
| Santo Ovídio | 2 | -51 | -69 | -56.70 | 3.92 |
| Santo Ovídio | 4 | -49 | -67 | -56.79 | 5.80 |
| Santo Ovídio | 5 | -48 | -68 | -58.08 | 6.11 |
| Santo Ovídio | 6 | -56 | -86 | -63.70 | 7.78 |
| Santo Ovídio | 7 | -52 | -84 | -62.28 | 8.95 |
| Santo Ovídio | 8 | -52 | -84 | -63.61 | 10.54 |

In spite of the overall good results, there were three specific beacons that didn't perform as well as the others, which were the beacons installed at Trindade station, at positions 3, 4 and 5. Starting with position 5, this beacon was never detected, thus not being referred on the results table. This was most likely a problem with the installation of the beacon, because even if it had very poor performance, it should be at least detected on close range readings. Having this in mind, this beacon was simply ignored. The same cannot be done about the other two beacons. As it can be observed in the data on the aforementioned results table, beacons at positions 3 and 4 in Trindade station have a much lower performance than the rest. During the readings, it was also observed that, from time to time, these beacons were harder to detect with the monitoring application, by having a lower detection frequency. The lower performance of these beacons can be a result of the fact that Trindade is one of the busiest stations where the monitoring was made, and even when not in rush hours, the platform is always very crowded, which means that there is much more signal interference and a harder propagation. This issue wasn't noticed on other stations because, other than Trindade, the most busy station in this line is S. Bento, and at this station, the beacons aren't at the same level as the platforms where the vehicles arrive, opposed to Trindade's beacons 3 and 4, which are right next to some of the platforms of this station. Although the performance of these beacons wasn't the best among the set, it should be noticed that their detection was always possible.

By looking at the data it is then possible to conclude that, in general, the solution adopted is most likely to succeed on underground stations, where users always have to pass near an area where at least one BLE beacon is installed. To address the fact that there may be cases of low performance of the BLE beacons, such as in very busy stations, or even cases where the stations' physical infrastructure or location create an environment more prone to interference or low propagation of the signal, a possible solution would be to create a more dense beacon distribution. By increasing the area covered by strong beacon signal, it is possible to reduce the probability of the user not getting a signal from the beacon, thus making its detection almost certain.

### 6.1.3 Long range light-rail readings

These test were performed on every station from Table 6.1 that is located at street level, namely, Hospital S. João, IPO and Jardim do Morro.

As explained before, these readings aim to test extreme use case scenarios, where users exit the vehicles at the very end of the street level stations, so four different cases were tested. Figure 6.1 shows a simple sketch of the layout of the IPO station, which is very similar to the other two, with the four locations where the readings were made labeled with the letters A, B, C and D. The data collected was grouped by these positions, and is summarized in Table 6.3.

Although the average values presented for long range readings could be interpreted positively for themselves only, because the average RSSIs are acceptable given the distance from the beacons at the reading positions, it has to be taken in consideration that values range from -77dB all the way down to -100dB, which can't be considered to be nearly enough for a platform that has to be

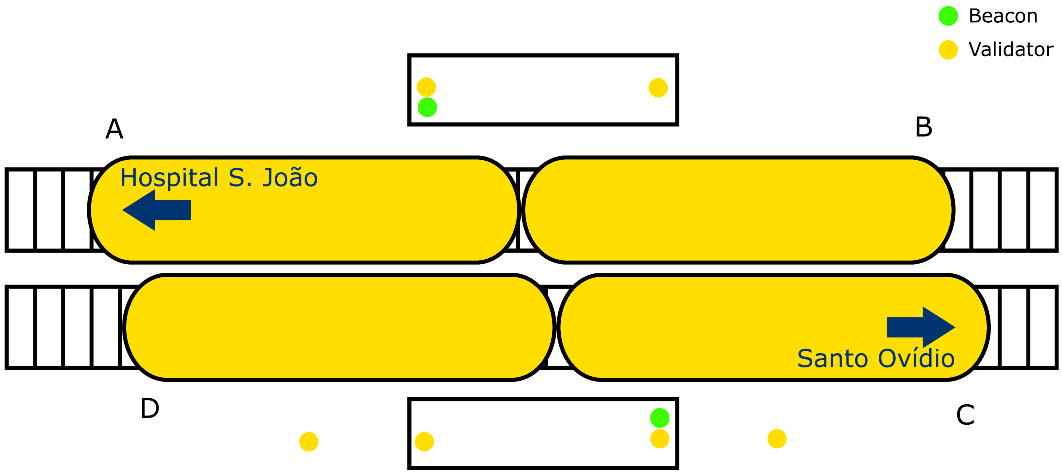


Figure 6.1: IPO station layout (street level station example)

Table 6.3: Long range readings results

| **Position** | **Maximum**(dB) | **Minimum**(dB) | **Average**(dB) | **Std. Dev.**(dB) |
|---|---|---|---|---|
| Position A | -81 | -100 | -87.16 | 5.71 |
| Position B | -77 | -99 | -85.50 | 6.09 |
| Position C | -80 | -98 | -86.31 | 5.98 |
| Position D | -80 | -94 | -85.24 | 4.47 |

reliable and dependable on. Also, these results do not account for a major problem that happened during the readings, which was the common case of not getting any signal from the beacons.

Not getting any beacons signal was a problem that happened on several occasions, when after putting the monitoring application on listening mode, no detections were recorded at all. Although on most cases some readings were registered, the fact that, on occasion, the beacons may not be detected, can jeopardize the effectiveness of the whole platform, as it creates the possibility of the users' trips not being correctly registered.

Another problem, on the same lines as the previous, is the fact that, when monitoring on long ranges, the frequency in which the detections are registered by the application is much lower than in closer ranges. This could also potentially mean that some users may not have their trips tracked correctly, because even though the detection of the beacon may even be possible, the rate at which the Anda applications receives the signal from the beacons may not be enough for it to be captured during the time the user exits the vehicle and continues his path, away from the station.

To address these problems, which essentially come from weak beacon signal reception, the solution that would probably be most effective would be the deployment of more beacons per station, creating a more dense beacon network environment. This solution would most likely succeed because, as it was observed with the close readings results, the beacons' signals at a closer range are more consistent, which would be a benefit for Anda, by making it a more robust platform.

### 6.1.4 Bus readings

On Table 6.4 are displayed the results of readings made on buses with Anda BLE beacons installed. As described before, reading on buses were made on four different places of the buses, namely ate the front and back of the bottom and the top floors.

Table 6.4: Bus readings results

| **Position** | **Maximum**(dB) | **Minimum**(dB) | **Average**(dB) | **Std. Dev.**(dB) |
|---|---|---|---|---|
| Front Bottom | -41 | -83 | -55.81 | 10.64 |
| Back Bottom | -58 | -88 | -74.77 | 6.63 |
| Front Top | -53 | -87 | -68.44 | 9.04 |
| Back Top | -61 | -94 | -79.95 | 7.49 |

To help understand the results of these readings, Figure 6.2 shows a box plot obtained from the bus data. This analysis includes the detection of outliers, and makes the data much more interpretable. By looking at the values obtained for each of the positions, the overall performance of the BLE beacons on buses is positive. At the front bottom of the bus, almost 75% if the readings were above -60dB, and other than the detected outliers, all of the readings were above -75dB. The front top and back bottom positions results weren't so good has the front bottom's, but were nonetheless very acceptable, with more than 75% of the data sitting above -80dB (the lowest readings were -75dB at the front top position, and -79dB at the back bottom position), and with no readings below -90dB. The position that registered the worst results, as expected, being the furthest away from the beacon, was the back top position, with quartile 3 at -77dB.

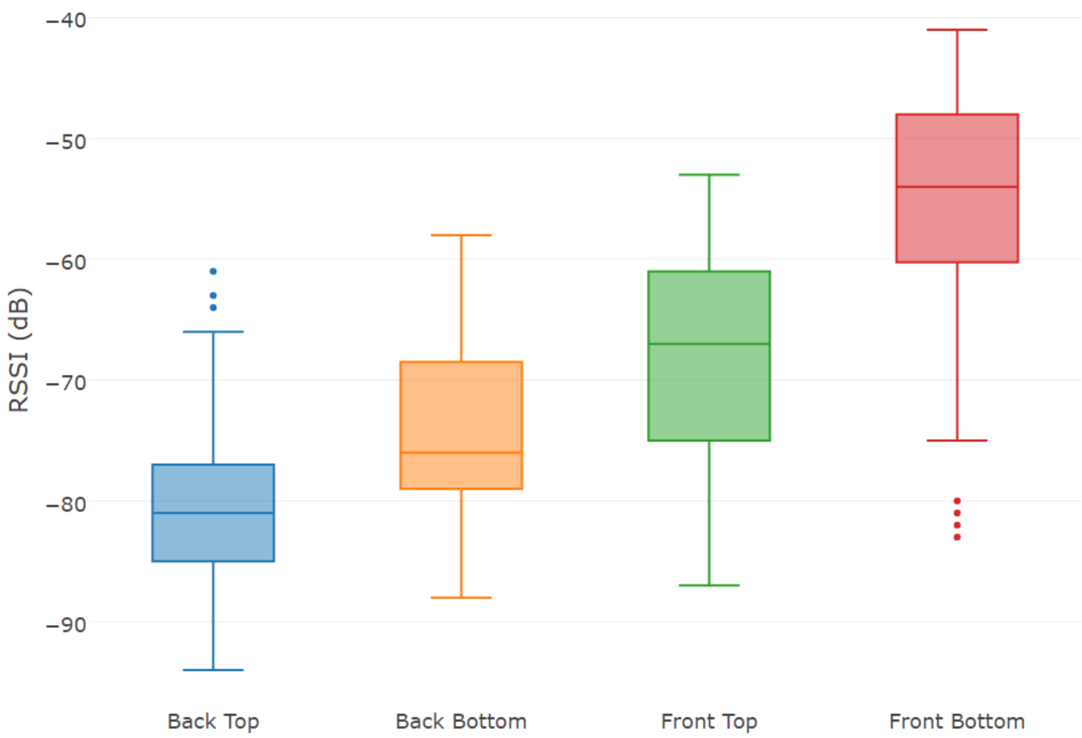


Figure 6.2: Bus readings

These readings were made during several different times of the day, including low traffic hours, where the vehicle was less than half full, and also rush hours where the capacity of the vehicle was at its limit. During the testing it was observed that although the beacons never ceased to broadcast its signal, when the vehicle was near its full capacity, the frequency of readings registered was below normal. This reduced performance is most likely a result of an excessive amount of devices interfering with the beacon's emitting frequency, and also of the fact that the propagation of the signal is unavoidably harder with much more physical obstacles than usual.

Overall, it can be concluded that the BLE beacons perform well on buses, in general, but their performance can be affected on extreme situations, such as being too far away from the beacon's location, or the vehicle being too crowded. One possible way to overcome these problems would be to install at least one more beacon on the bus, closer to the back of the vehicle. Although it wasn't possible to test this solution, given the results obtained from the current approach, it would most likely be enough to make the platform more reliable.

## 6.2 User feedback

As it happens with any new product, controlled and limited tests are not enough to validate the effectiveness of the developed product. The main goal of conducting a pilot test for Anda came from this need to validate the platform as a whole, which includes not only the mobile application itself, as well as the use of BLE beacons in the context of a mobile ticketing platform in public transportation.

Regarding the mobile application, the main concerns in the pilot test were user interface and user experience aspects. Although the participants in the pilot all attended a training session with the application, during the pilot some feedback was collected regarding the interface of the application, such as how it should behave during the trip process, namely on key moments of it (start and end of the trip).

The implementation of the use BLE beacons was another of the main aspects to be tested in the pilot test, and its evaluation relied essentially on the reports collected from the users. During the pilot test, users were given the opportunity to give feedback about their daily experience with the platform, via an email created specifically for this purpose, or by posting their feedback on a Facebook group only accessible for the pilot's participants. Both, the email and the Facebook group, were managed by people involved in the development of Anda, and every report was processed and forwarded to the correct team, either the problem is related to the mobile application interface, beacon detection or others. By getting these small reports, it was possible to make slight tweaks to the platform in order to avoid similar problems in the future, and strengthen the robustness of the system.

An analysis of these reports is important not only in the immediate context of the pilot program, in order to make the necessary adjustments for the users to have a functional prototype they can use, and assess the platform, but also in a broader perspective, as a means to evaluate the viability of the platform, and the main topic of this dissertation, the use of BLE technology in a mobile payment solution for public transportation.

### 6.2.1 Pilot test users

The users involved in the pilot test were chosen having in mind their usage of the public transportation lines in which BLE beacons were installed, namely the line D of Metro do Porto (light rail), route 500 of STCP (bus), and the connections between S. Bento station and Ermesinde operated by CP (train).

During the pilot test, every user was asked to answer a questionnaire to understand their use of public transportation, the general opinion on mobile payments and ticketing, their opinion about the possibility of a new mobile based solution for public transportation, and also some personal questions to help to understand the demographics of the chosen sample of users.

The pilot involved 83 users, 55% of them being male, and 45% female, and with ages ranging from 17 to 67 and summarized on Figure 6.3.

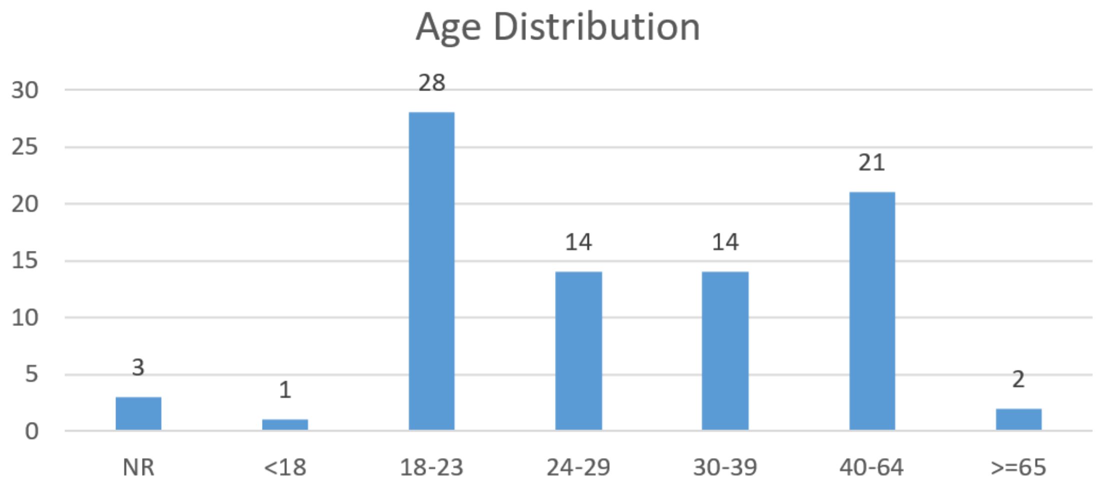


Figure 6.3: Pilot users age

Every user selected was required to own a smartphone, and to better understand how much experience users had with smartphones, one of the questions asked was for how long have they owned smartphone (Fig. 6.4). It was possible to conclude that a majority of the users owned a smartphone for more than two years, with only 6 users having owned a smartphone for less than 6 months.

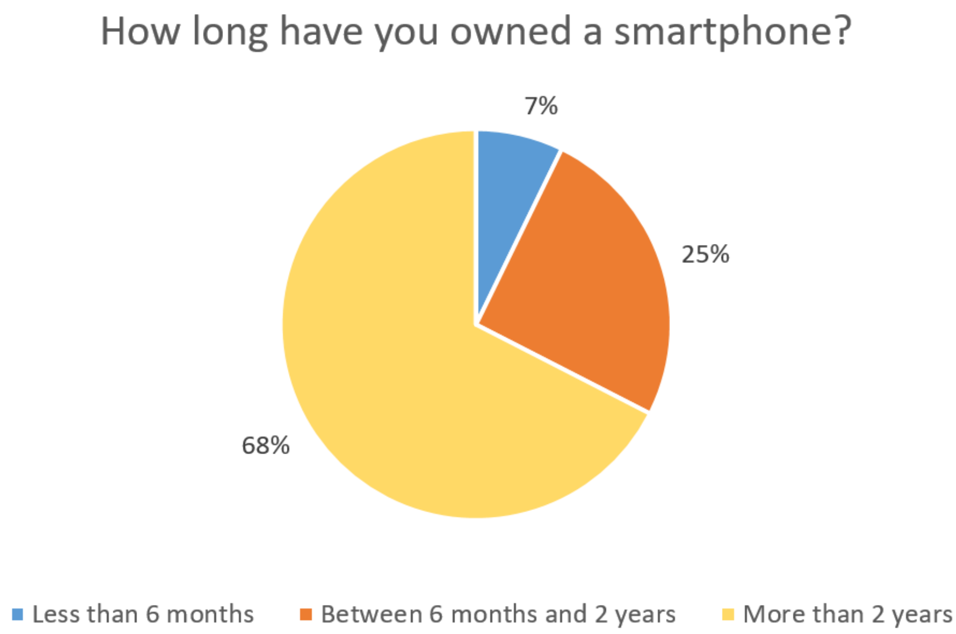


Figure 6.4: Pilot users smartphone ownage

The questionnaire consisted mostly on statements which the user was requested to rate from 1 to 5, according with how much they agreed on them. Each rating has the following meaning:

- **1** - Completely disagree
- **2** – Disagree
- **3** – Nor agree or disagree
- **4** – Agree
- **5** – Completely Agree

The ratings given by the users to some of the statements from the questionnaire are summarized on Table 6.5. For each statement, the number of responses to each rating is presented, with the most selected rating highlighted. As some users didn't rate every statement, an extra column was added, with the number of empty responses (NR).

The statements that the users were given to rate had the objective of understanding how beneficial would a mobile solution such as Anda be, by exploring some aspects of the users' opinion and experience with the current ticketing solution and their personal opinion on some of the concepts related to the new purposed approach.

The first two statements meant to understand if users had experienced some of the mains problems usually associated with Porto' public transportation ticketing system. Statement number 1 refers to the complexity of the zoning system, and the most selected rating was 1. Although this could indicate that most users don't experience this problem, it is important to notice that every participant in the pilot test was required to be holder of a monthly subscription of Andante before the pilot, so the user sample might be biased in this area, because they're most likely frequent travellers, and already know how the zone system work very well. In spite of this, one should also notice that more than 50% of the users answered with a rating equal or higher to 3, so they at least understand that the complexity of the zoning system might be a problem. The second statement is meant to ask the users if they ever were in a situation in which they had no means of buying tickets from automatic ticket machines, and it's possible to conclude that a majority of the users have been through this situation, with 71% of them giving a rate of 4 or 5.

Statement 3 suggests a comparison between the current and the new suggested approach, and compares the likeliness of the user to forget his phone and is Andante card at home. Once again, 5 was the rating that was most selected by the users, with 54.2% of the answers being above 3, meaning that the majority of the users agree with this statement. This means that a platform such as Anda would bring benefits to a big part of the users regarding the fact that it is made available through the users' smartphones, not requiring the need for them to carry an extra card, which in most cases they're more likely to forget at home.

Statements 4, 5, 6 and 7 all inquire the users about the topic of mobile payments and their advantages. In every statement, users most frequently completely agreed that mobile payments are beneficial, and for each of them, ratings of 4 and 5 were above 60%, with a peak of 75.4% on

Table 6.5: Statements' ratings from pilot test questionnaire

| Statement | 1 | 2 | 3 | 4 | 5 | NR |
|---|---|---|---|---|---|---|
| 1 - I have difficulty to understand which title type (Z2, Z3, Z4, ...) I have to buy to make a trip | **27** | 13 | 20 | 13 | 9 | 1 |
| 2 - I've been through a situation where I didn't have any cash to use the automatic ticket machines. | 9 | 4 | 9 | 21 | **38** | 2 |
| 3 - It's less likely for me to forget my smartphone at home than my Andante card. | 13 | 5 | 20 | 10 | **35** | 0 |
| 4 - Paying with smartphones is a good idea. | 4 | 4 | 12 | 19 | **44** | 0 |
| 5 - The use of mobile payments is compatible with my needs. | 6 | 4 | 17 | 20 | **36** | 0 |
| 6 - I believe that mobile payments allow time savings. | 1 | 3 | 21 | 21 | **37** | 0 |
| 7 - I'd like to use mobile payment services instead of traditional payment methods (credit card, cash, ...) | 4 | 8 | 21 | 20 | **30** | 0 |
| 8 - I'd like to use my smartphone to pay public transportation when this service becomes available. | 4 | 5 | 15 | 18 | **41** | 0 |
| 9 - The need to have a mobile data plan to make mobile payments is a negative factor. | 7 | 9 | 25 | 13 | **28** | 1 |
| 10 - The need to turn on GPS or Bluetooth to make mobile payments is a negative factor. | 8 | 13 | 20 | 16 | **26** | 0 |

statement 4. These answers mean that users are very receptive to the concept of mobile payments, which is of big importance since Anda aims to bring them to the public transportation.

The ratings of statement 8 help to conclude that a great majority of the users are interested in a solution such as Anda, with 71.1% of the users answering that they at least agree that if this service becomes available, they would be interested in using it.

The last two statements (9 and 10) were included to inquire the users about possible downsides of the described mobile solution, namely regarding the fact that it may require that the users have a mobile data plan, and also to have GPS and Bluetooth always turned on, while using the mobile application. The most common answer for both statements was 5, which suggests that these are negative factors to a large part of the users. Fortunately, for both statements, the second most selected rating was 3, suggesting that there is also a large part of the users that are indifferent to the fact that the application may have these usage conditions.

From the analysis of the statements ratings, one may conclude that it is likely that the public in general will be receptive to a mobile ticketing solution such as the presented, which is an important step on the implementation of the platform. Nonetheless, it is important to understand that, for the eyes of the users, there are also some negative factors, that may keep some them away from migrating to the new platform, so alternatives approaches must be considered.

### 6.2.2 User reports

As described before, one key part of the pilot was the feedback received from the users on a daily basis. Each report received from the users was analyzed, and used to improve some aspects of the platform. These improvements were usually immediately implemented, and if they were relative to the mobile application, they were deployed as new version of it, to which users were asked to update to. This allowed the development team to always receive feedback about the latest deployed version.

A total of 236 reports were received from the users, with several different areas where problems were found, or simply small suggestions of how the application should look like, or behave on some specific scenarios. The users were allowed not only to report problems, but also to share their experience with the platform, so some of the reports only refer that the application behaved as expected, with no visible problems. The positive reports account for 25 of the reports received, leaving a total of 211 problems reported. The reports were collected from April 1st to June 1st, 2017.

To have a better idea of the most problematic aspects of the developed prototype of Anda, every report was labeled according to the type of problem described. Table 6.6 shows the most common problems reported by the users. Not every problem reported fits in the presented labels, but were left out of this analysis because were mostly problems related with wrong usage from the users, smartphone errors, authentication, UI suggestions, among others, with minor relevance.

Starting at the bottom of the problem labels table, the *Beacon detection (distance)* label was set when the users noticed that the beacons weren't detected because they were too far away from them. The two cases reported were both on train stations, and both users were getting from one

Table 6.6: User reports most common labels

| **Problem label** | **Occurrences** |
|---|---|
| Beacon detection | 96 |
| End of trip | 10 |
| Beacon broadcasts wrong station | 9 |
| Server problem | 5 |
| Application crash | 4 |
| Vehicle without beacon | 4 |
| Bluetooth problem | 2 |
| Beacon detection (distance) | 2 |

train to another, not having to pass by the entrance/exit of the stations, thus not getting anywhere near the beacons. This use case wasn't considered when designing the pilot test, because as it was limited to only one train line, it was never considered that pilot users could possibly be going from a line included in the pilot, to one that wasn't. In the eventuality of an implementation of a platform like this, this type of use cases must be had in mind in every station, in order to make the experience seamless to the users.

*Bluetooth problem* was also a not very frequent label, with only two occurrences, on the reported cases, although it couldn't be confirmed with certainty, was most likely related with the fact that the BLE beacon detection, in some smartphones, requires the location services of the device to be turned on, and when they're not, it causes the application to throw an error message reporting a bluetooth problem.

The next problem, *Vehicle without beacon*, was reported by some users of one of the bus lines included in the pilot, that were made aware that the vehicle they were in didn't have any beacon installed. This happened because one of the vehicles in that line had to be replaced, and the company responsible for it didn't move the beacon to the new vehicle. Although this had some impact in the pilot, if this solution were to be implemented in the future, every vehicle on the fleet would have to have BLE beacons installed, so this most likely wouldn't be a problem.

There were also some reports of *Application crashes*. Unfortunately, only by analyzing the users' reports, it wasn't possible to link these crashes to any specific reason, which could even have been a result of external problems, not directly related with the Anda application.

The *Server problem* reports were all received on the same day, and were all caused by the fact that the main Anda server was offline during some hours, which prevented the users to be able to register trips with their smartphones.

*Beacon broadcasts wrong station* was a problem reported always at the same line, which coincided with the line that had the missing beacons problem. The devices that are connected to the beacons, and that supply the information that allows the beacons to change the information that is transmitted to the users' application according to the stop that the vehicles are currently at, would, sometimes, malfunction, and provide wrong information, causing the application to report different locations than the real ones. To ensure that this problem doesn't happen in the future, it must be checked that the back-end services provided by each operator at their vehicles is compatible with the deployed BLE beacons, in order to avoid problems such as the ones reported during the pilot.

The second most reported problem was related with the *End of trip*. Most of these reports stated that the application wasn't able to automatically end the trip. On all of them, users reported that even after having exited the vehicles a long time ago, the application still acted as it was on trip. As expected, these reports happened always with the implementations on which the beacons are installed in the stations (light rail and train). On the cases of the buses, with the beacons installed on the vehicles, the timeout that determines the end of the trip can be much shorter than if the beacons were on the stations, where the timeout must be set having in mind that users may be underground, without detecting any beacons, by a longer period of time. On the latest development versions of Anda, this issue was approached, and after some tweaks to the use of Android's API that allows applications to detect if the user is walking, the automatic end of trip became more effective. There was also record of a situation where, because the vehicle where the user was travelling had some mechanical issues, and had to stop for some time, and the application ended up closing the trip before it was in fact finished, because the timeout period had already expired. This situation is definitely not something that happens on a regular basis, but it is one that has to be had in mind in future versions of the system. One possible solution to avoid this problem would be to prompt the user before automatically end a trip, to confirm if the user has, in fact, exited the vehicle. The downside of this solution is that it would require an extra step for the user, reducing the simplicity of use that is one of the most important positive aspects of the application. To overcome this downside, an integration of the ticketing platform with the public transportation scheduling service could be beneficial. If the system received information about current problems and major delays on the public transportation network, it could notify the users that are currently making a trip on an affected line, and only in that situation, resort to the end of trip confirmation mechanism described above.

At last, the most reported problems were related with *Beacon detection*. All of the reports were referent to issues with the application not detecting beacons at some stations/vehicles. Among 95 reports, several causes for the problem could be identified. Some of the reports were ignored because consisted in normal behaviour, namely the cases where users reported that some stations weren't detected by the application. Most of these not detected stations were underground stations by which users passed during their trips, and that aren't supposed to be detected, as the beacons in them are installed in a different floor. All the users were given this information to avoid these type of reports in the future. Another very common problem was the application not detecting the last station on light rail and train trips, which lead to two distinct problems: if no other station was detected besides the starting one, it would cause the trip to never end, because the application has to have at least two stations to be able to register a trip; or, if there were other stations registered during the trip, the application would eventually end it, but with the wrong end station. Two main causes are believed to be the the origin of this problem. The first potential cause is the issue is described in section 6.1.3, and comes from the fact that on street level stations, where the beacons are usually installed more towards the center of the platform, if users exit the vehicles by one of its ends, the probability of not receiving any signal from the stations' beacons is fairly high. The second reason, and one that hasn't been had in mind during the beacon monitoring tests, is the possibility of excessive interference on the beacons signal when a vehicle arrives to a station, because at this point, several people are walking the same paths, all going through the beacons' covered areas at the same time. The physical barriers to the propagation of the signal created by people passing by the beacons can be enough to affect what the users will receive in the application. This possibility is the most probable cause to the issue, because the majority of the reports that noticed problems with beacon detection were registered at S. Bento light rail station, and Campanhã train station which are two of the most busy stations that were included in the pilot. At S. Bento, for example, when a vehicle arrives at the station, there may be several dozens of people simultaneously exiting the station, consequence of being located at the center of Porto, and also by having a connection with the train network. To confirm this possibility, further testing is needed. A continuous monitoring of the signal emitted from the BLE beacons could be ideal, as it would allow to analyze how the signal strength varies along the different times of the day. If the problem is, indeed, related with high concentration of users on the beacon's proximity, maybe some other approaches should be tested, specifically different beacon positioning. One of the possibilities would be to try to install the beacons at a higher position, such as the ceiling. A higher position would allow the beacon's signal to go through a greater distance before reaching any physical obstacle, and potentially get to a larger number of users. Another possibility would be to, as suggested for other cases, increase the number of deployed beacons to each station, which would make the beacon detection less likely to fail.

# Chapter 7

# Conclusions

## 7.1 Synthesis

Throughout this dissertation, a close look to an implementation of the use of BLE beacons as part of a mobile ticketing solution for public transportation was taken. A pilot test regarding this approach was started in the city of Porto, so this dissertation was integrated with that project, and the analysis presented is a result of that integration. In order to give context to the aforementioned analysis, the current ticketing system of public transportation in Porto was described, and a detailed description of the solution implemented for the pilot test, including how BLE technology was integrated in said solution.

To assess the implementation that was tested during the pilot, two main areas were explored: beacon signal monitoring, which is a more technical approach, and user feedback analysis. As for the beacon signal monitoring, several tests were made, either for the on-vehicle and on-station approaches to the BLE beacon installation, and for different distance ranges. From these tests it was possible to conclude that, at close to medium distances, and in regular usage scenarios (not rush hours), performed well, or at least, well enough. At long distances and/or in locations with higher user traffic, the measured performance wasn't so acceptable. The user reports analysis focused on trying to understand the problems that the pilot test users faced during their daily routine, while using the platform. It was also possible to identify some issues, with the most common problems being issues with beacon detection, and other consequences of that same problem. These results suggest that the tested implementation, as is, isn't reliable enough to be considered as a final product but the pilot test has had its success, as it was possible to assess the viability of the BLE technology in this context, and to make some suggestions about what can be changed in the future in order to make a platform like the one tested more robust, and dependable on.

In order to improve the described mobile ticketing solution, some suggestions were made, that could improve the reliability of the presented solution. One of the suggestions is the increase of the number of deployed beacons at each station, for the light rail and train approaches, where the beacons are installed only at the stations. This suggestion is of special importance at high traffic stations and outdoor, street level stations, where the tested approach also turned out to be flawed.

The same principle applies for buses, where a higher number of beacons on-board would make the system more robust, and less likely to fail.

## 7.2 Contributions

The analysis of the results obtained allowed a better understanding of how a platform that uses BLE technology, by means of bluetooth beacons, as a tool for a mobile ticketing for public transportation system performs, and if its implementation could be viable. The outcome of this analysis is that the technology can be used to achieve the desired goals but, as it was implemented in the solution that was analyzed in this dissertation, it still shows some flaws that need to be addressed. Nonetheless, the described solution, although in need of some final adjustments, represents an effective way of implementing a mobile ticketing platform that offers a seamless experience to the users, by enabling the possibility of tracking their trips from beginning to end. The flexibility of this solution makes it suitable to be used in virtually every existent public transportation network, even the most complex cases, with several different operators spread by different means of transportation.

## 7.3 Future Work

After the testing was finished, and all the data analyzed, it was noticed that to be able to troubleshoot the issues that were found and reported during the pilot test, a more thorough monitoring process would have been beneficial. For example, a continuous BLE beacon monitoring during the duration of a full day would allow to better understand how the performance of the beacons is affected by different levels of user traffic at the stations. Also, a controlled monitoring with several phone models, and operative system versions would be beneficial to understand if some problems detected by a few users were directly related with their devices, or something that could eventually happen to any user.

As it was mentioned before, some possible solutions were presented as a response to some of the problems that were found, and one of the next steps could be to implement this solutions, in order to check if they're viable and able to solve the problems they were designed to address. The changes to the current implementation that would most likely have a positive effect on the platform are the increase of the number of deployed beacons to the most problematic stations, and the installation of beacons on different locations at the stations.

After the problems with the detection of BLE beacons get completely solved, an important step that has to be taken before a solution such as the described can be deployed to a final product, is the development of a security layer at the level of the BLE beacons. To avoid hacking of the platform and possible fraud, it is advisable the implementation of some security mechanism that allows to verify the beacons' signal authenticity by the users' devices, and prevent the effectiveness of eventual spoofing attacks.

Also, in order to fully integrate this mobile ticketing solution with an existing public transportation ticketing system, there is the need to implement an inspection mechanism that is compatible with the existing platform. The platform that was analyzed already has part of a possible implementation of the inspection, but only at user side, with the inspection agents side still not designed.

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# Appendix A

# Anda Screenshots

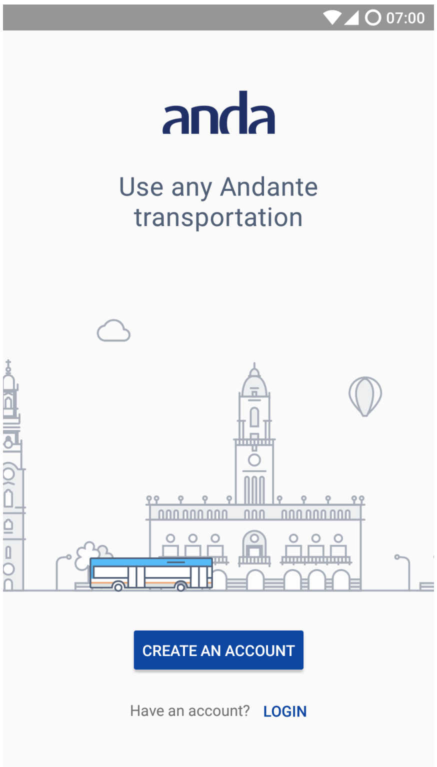


Figure A.1: Landing Screen

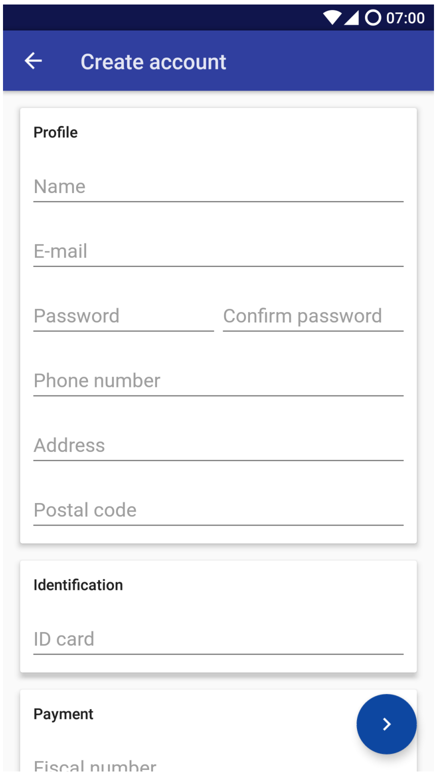


Figure A.2: Registration Screen

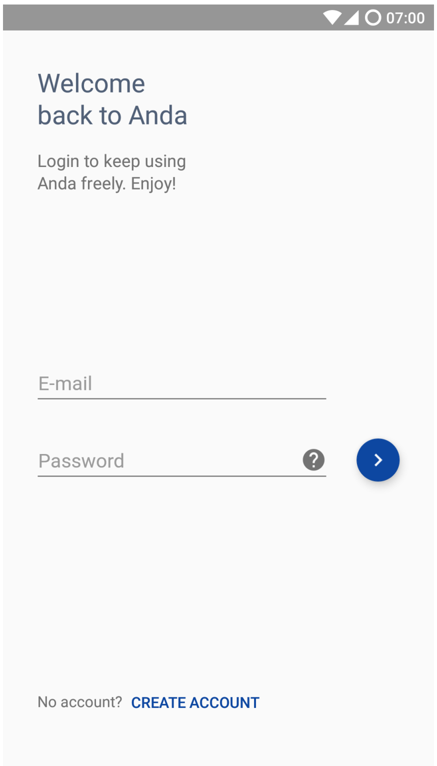


Figure A.3: Login Screen


Figure A.4: Start Selection Screen

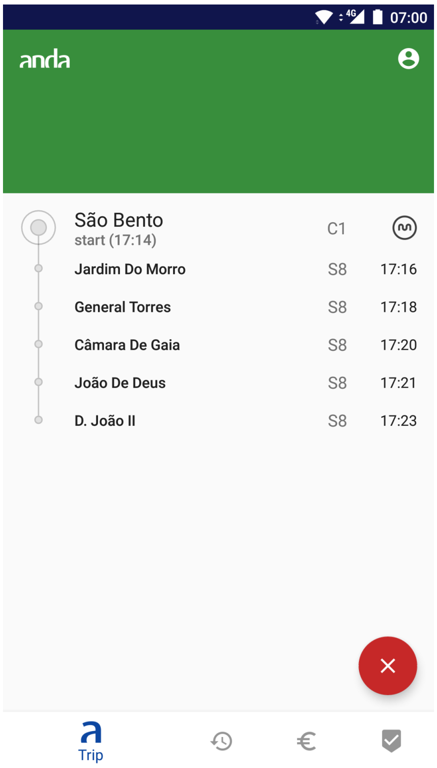


Figure A.5: Ongoing Trip Screen

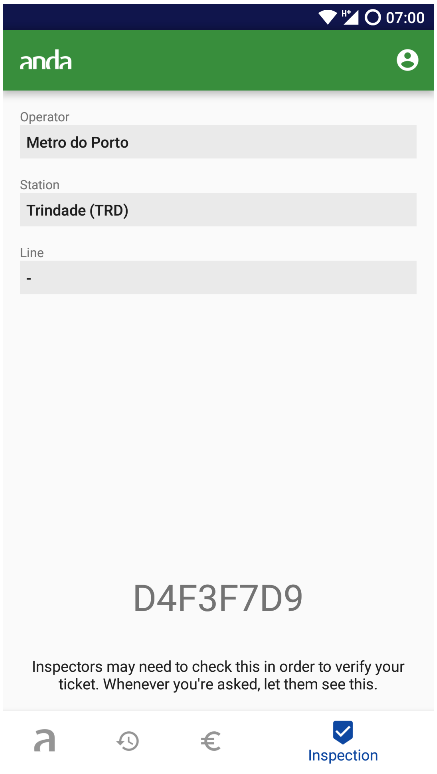


Figure A.6: Inspection Screen

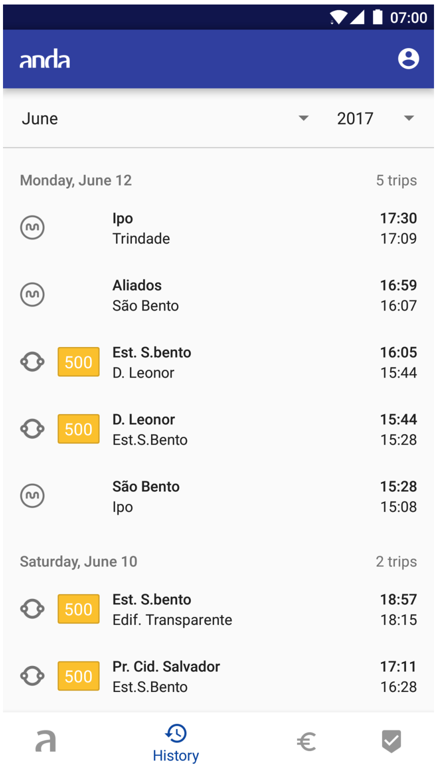


Figure A.7: Trip History Screen

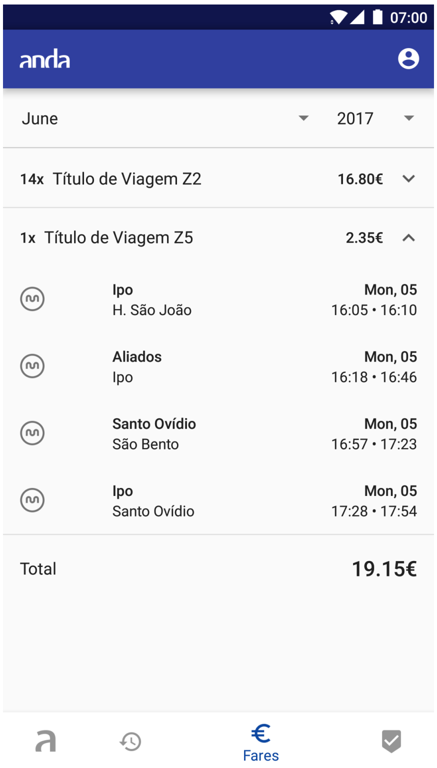


Figure A.8: Tariff Optimization Screen

Anda Screenshots

# Appendix B

# Light Rail Stations' Layouts

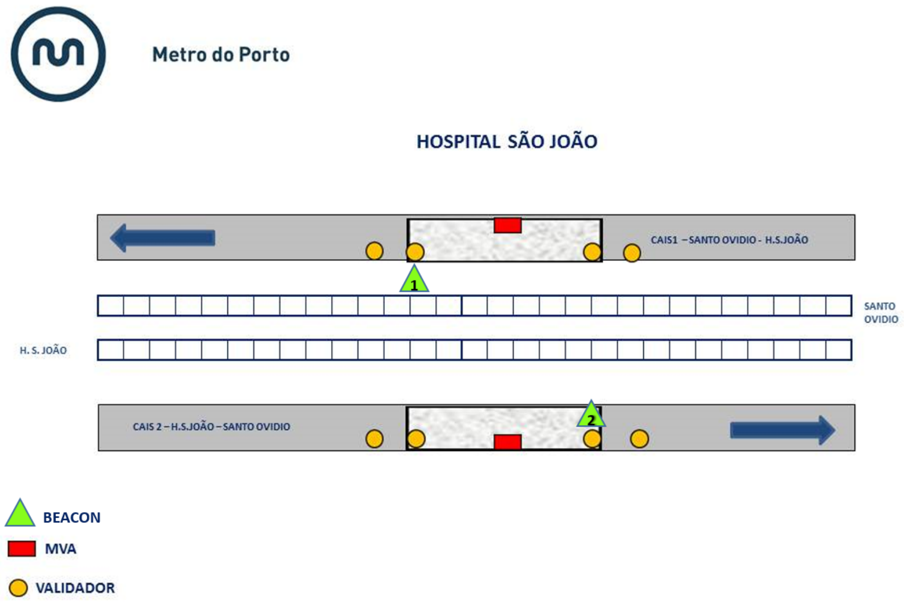


Figure B.1: Hospital S. João Station Layout

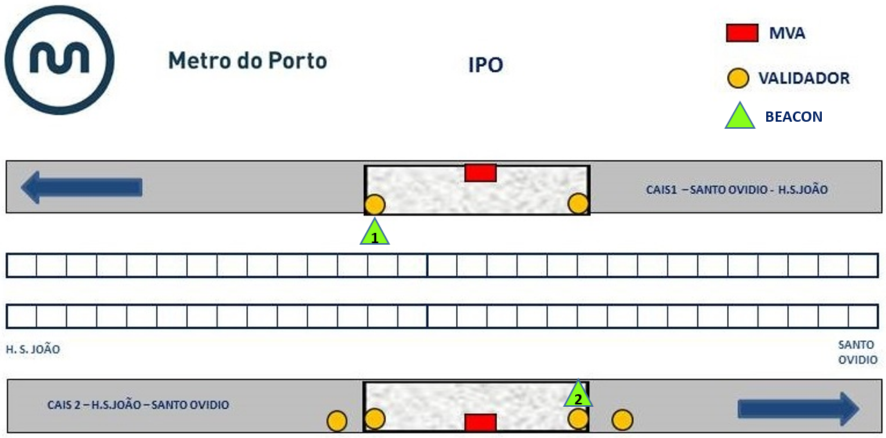


Figure B.2: IPO Station Layout

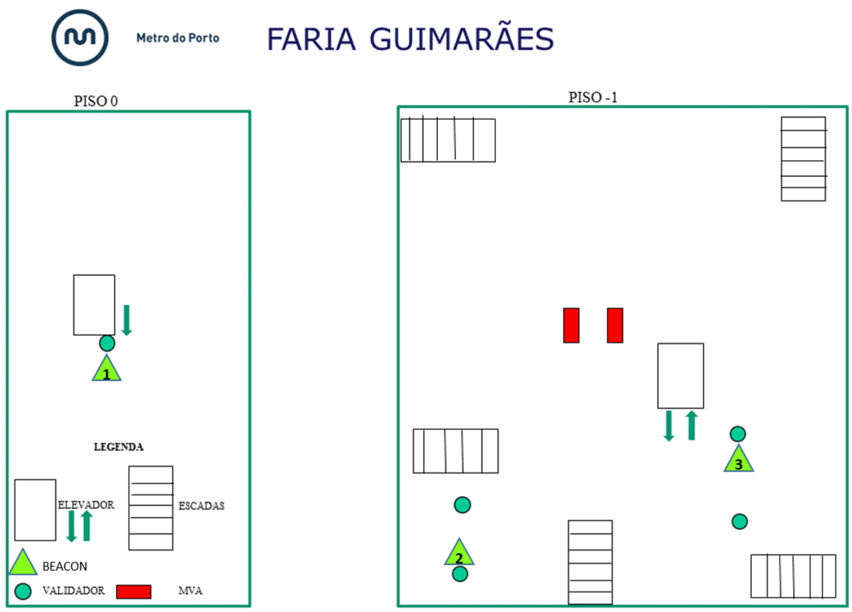


Figure B.3: Faria Guimarães Station Layout

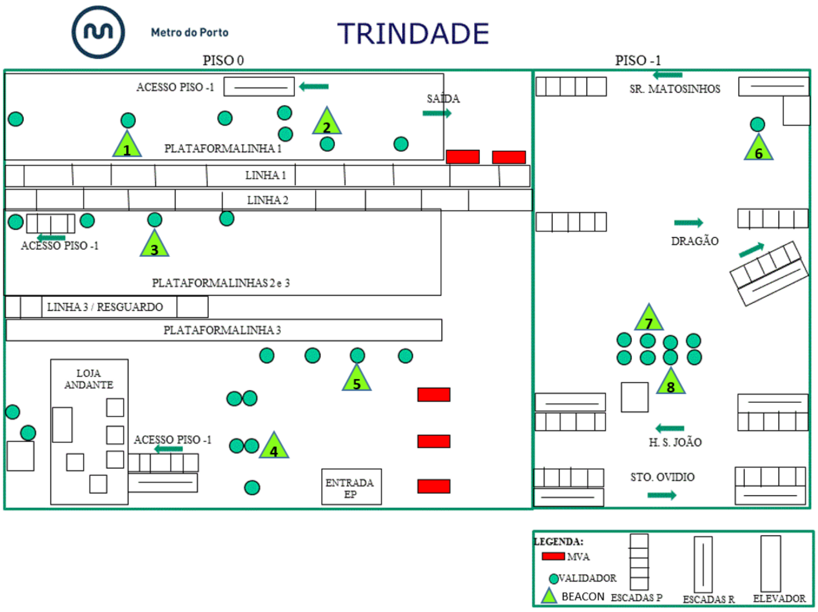


Figure B.4: Trindade Station Layout

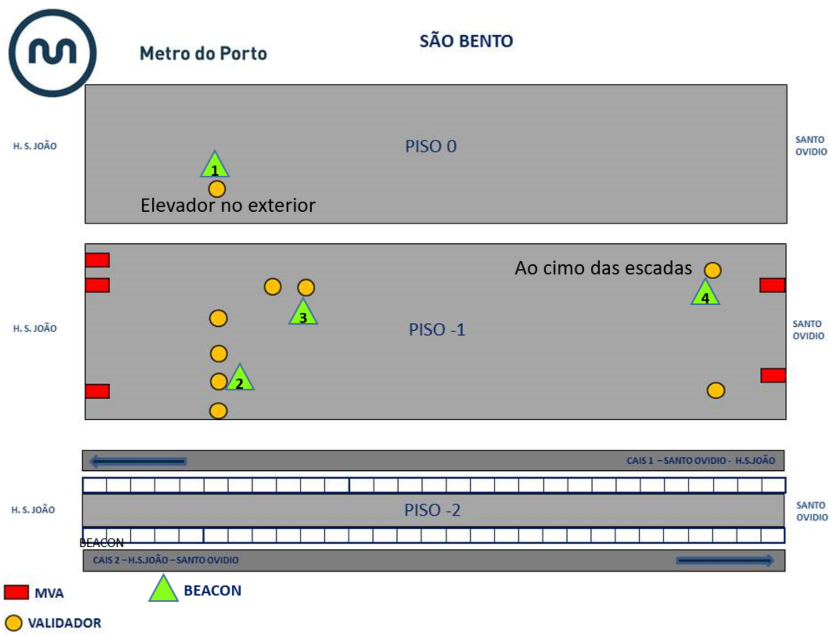


Figure B.5: S. Bento Station Layout

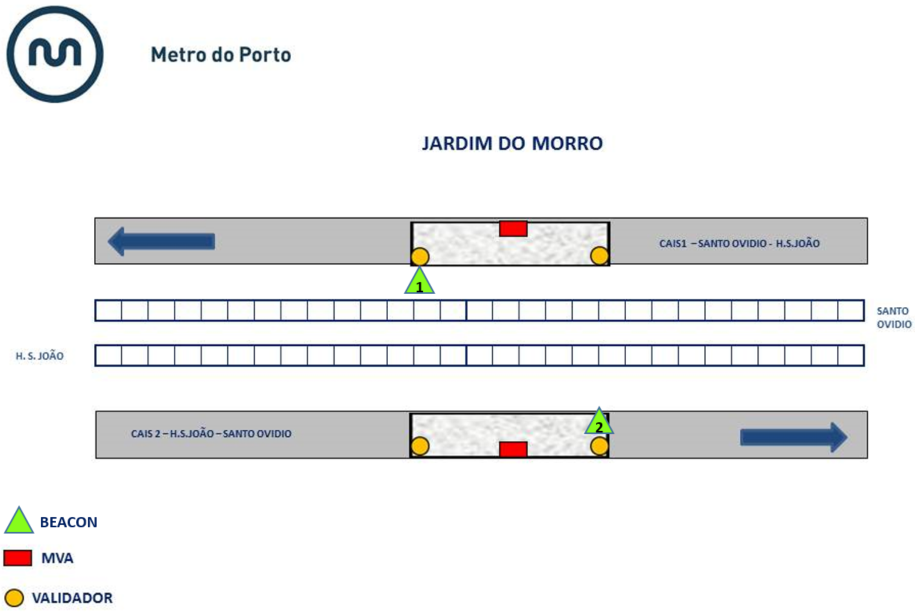


Figure B.6: Jardim do Morro Station Layout

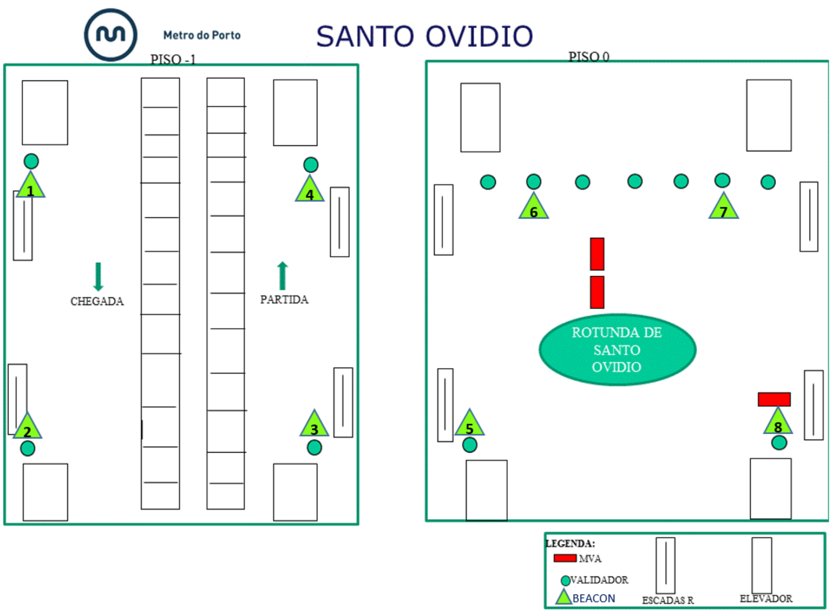


Figure B.7: Santo Ovídio Station Layout