Automating Ticket Validation: A Key Strategy for Fare Clearing and Service Planning

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***Abstract*— In order to achieve a sustainable mobility environment, an efficient public transport framework, in which different means and companies coexist, is essential. An integrated fare system thus needs to exist, along with an agreement among the service providers for ticket revenue sharing (clearing), to avoid creating a barrier to the adoption of public transport, since users tend to be overwhelmed by many tickets and several purchase methods. The results of an extensive review of the current state of the art, regarding the possible solutions for ticket validation, which can be provided to the users by the service providers, lead to identifying a solution, whose aim is to combine the needs of both users and providers, by developing a system to simplify user experience, while at the same time collecting precious data for service monitoring and planning. This will be practically achieved through a flexible ticket validation system which will make use of three different technologies (QR codes, GPS and Bluetooth). The contributions of this work are: i) greater flexibility in ticket validation obtained by using multiple technologies; ii) the novelty of a gamification layer applied to mobile ticketing; iii) the identification of a method for obtaining clearing-related data. The adoption of multiple technologies introduces different benefits: to the users, who will be able to complete trips on multiple vehicles without worrying about ticket compatibility; and to the companies, who will be free to choose among the multiple options, and will thus not be forced to adopt a single technological solution. The main expected result is the collection of key validation related information, which will be exploited mainly for clearing purposes and possibly even in real time for optimizing fleet management.**

Keywords—Bluetooth, gamification, GPS, public transport, smart ticketing, sustainability

I. Introduction

It has already been proven that an integrated fare system can trigger a modal shift towards public transport, which can lead, in the long term, to a significant increase in the number of sustainable modes users [1]. However, it is also important for this system to be both user friendly and fair for the public transport providers, especially in an urban environment in which several modes and providers coexist. For this to be possible, a fair ticket revenue breakdown system (clearing) has to be employed, to regulate economic relationships among the different companies. One of the best strategies to achieve a clearing agreement makes use of the number of passengers served by every provider, to measure how much revenue each one of them is owed. This kind of data can be obtained either through systematic surveys or by taking advantage of data registered by the companies' ETS [1] [2]. Given recent developments in technology, which lead to widespread access to mobile devices, it would be unwise not to consider mobile ticketing, achieved through smartphone applications, as an essential tool to help solve many of the aforementioned issues. As a matter of fact, transit companies are also constantly trying to exploit new findings, especially in ICT[2], to offer services aimed to improve passengers' journeys and to "modernise" their public image, in order to expand their user base [3].

This paper aims to describe a prototype which will aid public transport users, actual and potential ones alike, by making the whole validation process simpler and faster, while at the same time allowing the companies to record a large amount of data, useful both for service optimization and clearing purposes. Section II presents an extensive review of the systems currently available and of similar already implemented projects. In section III the proposed system is described in detail. Section IV describes the first tests performed and the resulting data. In section V, a summary of the work still needed is given. Finally, section VI sums up the results and conclusions of the paper.

II. State Of The Art

Literature relating to electronic ticketing offers various methods to differentiate among the many possible options currently available. First of all, it is important to consider the classification of the more commonly used schemes of user actions when entering and leaving the transport vehicle, which are:

- Check-In only (CI), where the user only has to act when boarding a vehicle, to be recognized by the system;
- Check-In Check-Out (CICO), where the user has to act both when boarding and when alighting;

[1] Electronic Ticketing System
[2] Information and Communication Technology

- Check-In Be-Out (CIBO), where the users only have to act when boarding, but their alighting is automatically detected by the system;
- Be-In Be-Out (BIBO), where the presence of the user is detected automatically both while boarding and when alighting, requiring no action whatsoever [4].

The CI alternative is probably the most widely used, since it can easily be applied even with traditional paper tickets, while the others require more specific systems to be implemented. Another classification to consider is that of the different media in which an electronic ticket may reside, that is:

- Smart cards, usually credit card sized plastic supports containing a chip, which use either a contact-based or contactless interface of communication [5];
- Mobile devices, where the ticket is registered on a phone / smartphone and implemented through SMS (Short Message Service), optical recognition or Near Field Communication (NFC) [6].

The most well-known examples of a smart card based system are probably the Octopus Card in Hong Kong and the Oyster Card in London. In both cases the system is CI only for the most part, but in some circumstances CICO is necessary, specifically for light rail in Hong Kong [7] and for the "Tube" in London [8]. In Italy, a similar system exists in the Piedmont region, where the BIP[3] card uses a CICO scheme in some selected provinces [9]. On the other hand, mobile ticketing is probably a lesser known tool, and it is not as simple to find many successful examples. However, SMS based systems can be found all over Europe, for example in Milan [10], Helsinki [11] and Prague [12]. Mobile ticketing based on smartphone apps is also available, in Rome [13], Porto [14], Stockholm [15] and Venice [16].

The automation provided by CIBO and BIBO is still a relatively new concept, and as such the number of successful real world applications is very limited. A continuous gathering of validation data from such a system would allow to build a more complete and reliable database. However, in non-gated transportation infrastructures, users often choose not to check-in for every trip, and, furthermore, average travel times can be obtained only when a system registering both check-ins and check-outs is in place [4]. That's why a BIBO scheme, which removes the uncertainty connected to user action while at the same time recording completed trips, could prove to be one of the best methods currently available for improving public transportation as a whole.

One of the first concepts for a BIBO system was presented by Ericsson in 2001, who tried to use standard Bluetooth, but no further developments emerged. In 2004, in Switzerland, the company "ATRON" showcased a CIBO prototype, which used a WLAN[4] antenna to check if the devices carried by users were still on the vehicle, but this system never left its laboratories. Again, in 2007, the Swiss Federal Railways issued a "Request for information" to the industry, to identify a BIBO solution for all national public transport. The companies suggested various solutions which used diverse technologies, such as RFID[5], NFC, WLAN and GPS location [4]. This ultimately led to the development of two smartphone apps, "FAIRTIQ" and "lezzgo", but they both have the features of a CICO solution [17] [18].

The first BIBO system presenting documented large scale tests is the "ALLFA" project, developed by Siemens in 2005. ALLFA was tested in Dresden, and was based on a previous (2001) field test performed in Switzerland (EasyRide). The users enrolled to conduct the test received an electronic device, either a "smart card" or a mobile phone. The devices were equipped with a radio frequency communication interface, whose signal was automatically detected by antennas mounted inside the vehicles, when boarding and when alighting. 54 vehicles were equipped with the antennas (different models), and almost 2,000 customers took part in the testing. The customer surveys conducted before and after the trial indicated that 42% of the pilot participants stated they were likely to use public transport more frequently thanks to ALLFA's ease of use [4].

A proof of concept Android App was developed and tested in 2014 at the Norwegian University of Science and Technology. The system aimed to automate ticket validation at events (museums, concerts, *etc.*) by installing BLE[6] beacons at the various venues. The simplified app was tested by a small group of individuals, but the results seemed promising [19]. This system apparently registers only the entrance of the users at the venue, so it could be classified as a BI (Be-In only) scheme, but adding a BO (Be-Out) function could be trivial.

In 2015, Graz University of Technology proposed an RFID based system to detect passengers boarding a bus and subsequently alighting [20]. No further information was found on any subsequent practical implementation. In 2016, software engineers, at Johannes Kepler University conducted several tests to prove whether or not BLE was suitable for public transport BIBO systems. Although they did not test a mobile ticketing app, their measurements, while not covering every possibility, showed very positive results for this technology [21].

In 2017, a BIBO concept app, which interacted with BLE beacons, was developed in the Netherlands. The preliminary study regarded many aspects strictly related to a mobile ticketing app, like security and privacy, battery consumption, accuracy of the validation. The simplified app was tested in a makeshift mini bus by 20 test users, to evaluate how the app was perceived [22]. In the same year, a mobile ticketing prototype app which used BLE technology was developed for Porto's intermodal public transport network. The system supposedly tracked each user's trips from beginning to end, thanks to BLE beacons installed on specific buses and stations. The system included delayed billing and tariff optimization, and was tested by 83 users [23]. However, the system was later converted to a CIBO layout, which keeps the BLE functionalities for the BO operations, while using NFC validators for check-in [24].

Moving on to recent large scale BIBO experiments, a system developed by the company "Turnit" was recently used in the Estonian city of Tartu. The system automatically

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[3] Biglietto Integrato Piemonte
[4] Wireless Local Area Network
[5] Radio Frequency IDentification
[6] Bluetooth Low Energy

detected passengers boarding and alighting thanks to BLE beacons installed on the buses. The first phase involved 73 participants, who completed over 2,500 trips [25]. Soon after, testing phases started, engaging many more users, which ended in March 2018. During this period, about 2,500 testers completed over 60,000 trips using Turnit BIBO. However, the system was not found to be completely successful and testing has been stopped for the time being. Many problems were encountered, since often it was impossible to ensure that the validation process worked correctly (or at all) on the passengers' phones. While the hands-free system is not currently used, it is still being developed to perfect its reliability. Feedback from the testers showed that a BIBO system is both welcome and convenient [26].

While past experiences relied solely on a single technology, be it Wi-Fi or Bluetooth, the system which will shortly be described can work both as a CIBO and a BIBO system, using many options at the same time: QR[7] codes, Bluetooth, GPS and accelerometer. This also means that it will be able to work in many different combinations, given both by the users' smartphones and the vehicles' configurations. As an example, if a bus is equipped to work with Bluetooth, and the users choose to have both Bluetooth and location services active on their smartphone, all the options can actively be used and BIBO is available. However, if the user does not activate any of the sensors, the system will still work as CIBO but only using QR codes and accelerometer. On top of that, a gamification layer will accompany the users through the whole process, to encourage them even more to use the innovative validation system by handing out virtual rewards. As far as the authors know, this kind of system has never been used in association with electronic ticketing. The whole system is described more in detail in the following section.

III. The proposed solution

A. Preliminaries

This analysis was developed as part of the cluster project "SIMPLE" (StrumentI e Modelli Per La mobilità sostenibilE – Tools and models for sustainable mobility), which aims to implement ICT solutions in sustainable mobility [27]. SIMPLE involves many public transport operators, covering most of the Sardinian region (Italy). In particular, the partner companies are:

- ARST, which offers a suburban bus service throughout most of the region, while also providing urban bus transport and light rail service in some municipalities [28];
- ASPO, which runs urban buses in the city of Olbia [29];
- ATP (Sassari), which runs urban buses in the city of Sassari [30];
- ATP (Nuoro), which runs urban buses in the city of Nuoro [31];
- CTM, which operates in the Metropolitan Area of Cagliari with an urban bus service [32];
- Autolinee Baire, which manages private coach hire, but also offers some public transport connections [33];
- Mereu Autoservizi, which operates in a fashion similar to Baire [34].

CTM already offers their passengers the option to use their proprietary app "BusFinder" (available for Android, iOS and Windows Phone) to receive news about the state of the service, to check real-time vehicle transits at bus stops, and to buy and use their tickets. The same can be said for ATP Sassari and their homonym app (Android and iOS). Currently, the regional regulations [35] require ticket validation only when boarding, while check-out operations are not mandatory. The validation through BusFinder and ATP Sassari happens by scanning a QR code placed inside any bus, whenever boarding it [36] [37]. This means that, currently, the system is CI, while CICO is optional.

B. Proposed Architecture

Many of the previous studies included a system to automatically pay for tickets, in some cases even with a "pay as you go" model. However, the proposed prototype focuses only on a system that automates ticket validation, leaving open the possibility of adding the automated ticket purchase at a later stage of experimentation. Fig. 1 shows the different sets of actions that the user has to carry out when using the smart ticketing app, both now and when the proposed system becomes operational. We assume that the users, whenever they want to travel using PT, must have a valid ticket, purchased on the app; they must then validate it for the bus ride. The diagram on the left of the figure shows the sequence of operations required to use the current system, while the right one indicates the set of different actions needed when the automatic features become available.

Specifically, currently users, after boarding the bus, must open the app, access the ticket menu, select the correct ticket, start the validation process by pressing the "validation" button, scan the QRcode on the vehicle, and finally get off the bus when they arrive at destination. Every time they board another bus, the same steps must always be repeated, from opening the app to scanning the QRcode.

When the new automatic validation features proposed in this work become available to passengers, the user who wants to use PT will have to follow some steps similar to those of the current system. After having purchased the ticket, the passenger will board a bus, start the app, access the ticket menu, and choose the ticket to be automatically validated to be active. These steps will have to be taken only once for every ticket or seasonal pass, and the user will follow them again only when a previous ticket has expired.

However, the users will have to activate the Bluetooth and the location services on their devices whenever they want to use automatic validation, so they will either have to leave them always on, or remember to activate them before using PT. In order to affect battery life as little as possible, smartphones will communicate with the system only when necessary. The users will then only need to get on and off the buses, and will simply receive check-in and check-out notifications.

[7] Quick Response

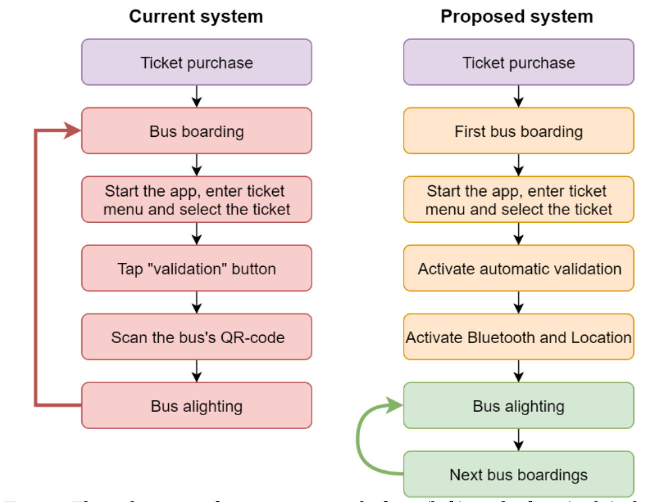

Fig. 1. Flow diagrams for user actions before (left) and after (right) the introduction of automatic validation

The new system will expand the current one (*i.e.* BusFinder and ATP Sassari), allowing to validate tickets with more than one of the technologies installed on modern smartphones. As a matter of fact, the new prototype will add the option to use it as a BIBO system, giving the users a completely hands-free experience. These results will be achieved using, at the same time, the Bluetooth, the accelerometer and the location service, which can all be found on most (if not all) smartphones, while keeping the current QRcode system. These services can work either independently or in combination, by taking into consideration each user's smartphone configuration. Most of the used technologies are already well-known:

- QR codes are two-dimensional barcodes usually containing information related to the item to which it is attached; it usually consists of black squares arranged in a square grid on a white background, which can be read by a camera, and processed to extract the data it contains [38];
- the smartphones' location services allow the apps to access the data gathered by dedicated antennas from the satellite system (GPS, GLONASS); these raw data are then used to determine the position of the smartphone on the planet's surface [39] [40];
- the accelerometer installed in most smartphones registers relative accelerations on its three axes; these data are processed by dedicated services, which, through an algorithm, manage to determine the kind of activity [41] [42];

However, Bluetooth, being one of the cores of the project, requires a more detailed description. Bluetooth is a wireless technology standard for exchanging data over short distances using radio waves in the 2.4 GHz band from fixed and mobile devices [43]. More specifically, Bluetooth Low Energy (BLE) is an evolution of the basic system, requiring considerably lower power (months or years of autonomy can be achieved using a single button cell) with a small size and low cost [44].

A BLE beacon is a device that broadcasts a series of identifiers, enabling receiving devices to perform one or more actions. Beacons can operate by using different protocols, like iBeacon, AltBeacon or Eddystone [45]. Among these, iBeacon, developed by Apple Inc., is the most successful. An iBeacon advertising information provides the following:

- a UUID[8] (16 bytes), which identifies the app or the deployment case;
- a Major (2 bytes), which can specify the use case;
- a Minor (2 bytes), which can specify the sub region.

These values can be totally customised to fit any and all possible real world applications, and are not restricted by their definition [46].

After installing the beacons in their physical location, smartphone applications can interact mainly in 2 ways:

- Region Monitoring – a region can be defined by at least a UUID, and the system can understand when a device enters or exits one of these regions;
- Ranging – when the system enters a region, it can start "ranging" all the beacons therein, that is an approximate level of distance is returned as one of four categories (immediate, near, far or unknown) [46].

In addition to these values, when advertising an iBeacon will also return a value for "accuracy", the accuracy of the proximity value measured in metres from the beacon (which is not the actual distance from the beacon itself) and one for "RSSI", received signal strength indicator, the average value of the power level samples received from the beacon [47].

The new system will complement the current one, not removing any of its core functionalities but instead adding new ones. For example, a user could still decide to use QR codes for both check-in and check-out operations, and his experience would remain mostly unchanged. Moreover, the current functionality will always remain available, since an error in the system could prevent the automated process, but users should never be unable to validate their tickets.

The system will include three main checks to assure the automated process is working correctly:

- "Boarding check" - to make sure a user has actually boarded the bus, and is not simply in the vicinity while the bus is passing by;
- "Permanence check" - after the boarding check, the system makes sure the passenger is still on board the bus, to effectively measure journey duration;
- "Alighting check" - to verify with certainty that a passenger has left the vehicle.

As shown in Fig. 2, all three systems will work towards each check, and for every T consecutive second:

- The "Bluetooth" module will check if, based on the UUID and major values, the received power rises over a P dBm threshold (boarding), stays over this value (permanence) or drops below it (alighting);
- The "location" module will check, considering a $\pm N$ metres margin, if the path followed by the user starts following the same one as a bus (boarding), if it remains on the same path (permanence) or if the

[8] Universally Unique IDentifier

user starts following a path not compatible with any bus (alighting);

- The "accelerometer" module will check if the data indicate the user started riding a vehicle (boarding), keeps moving while on a vehicle (permanence) or stops riding and starts walking or stays still (alighting).

After a successful "boarding" check, the system will automatically perform a check-in, and in the same way will automatically check-out after a successful "alighting" check. The values for the *T*, *N*, and *P* parameters will be defined after analysing the calibration test results.

C. Additional Hardware Devices

While location and accelerometer functionalities do not require any additional components, BLE requires hardware beacons to be installed inside the buses. Since, during a testing phase, a wide set of options is preferred, a BLE beacon providing a good level of customization was identified. The choice fell on a beacon produced by "BlueUp", which offers 4 different slots configurable with iBeacon protocol, and 4 more slots configurable as Eddystone, with complete customization. These beacons contain a Nordic Semiconductor nRF51822 module and are powered via a replaceable CR2477 battery [48].

As of now, only the iBeacon protocol has been adopted when configuring the beacons used during testing. They were configured using the UUID as the system identifier, the Major as the bus and company identifier and finally the Minor as the beacon identifier inside the bus.

D. Additional Software Functionalities

To measure the permanence of a user on board a bus, the new features will be added to an already existing app, in the cases where it is already supplied by the company, or alternatively a completely new app will be developed for the cluster companies that do not already have one.

After updating the user app, the new features will be presented, by means of pop-up dialogs:

- The app will first inform the user of the new features available to simplify the actions to be taken while traveling on public transport buses; the user will be invited to activate the services (sensors) needed to use these new functions, while still being able to choose not to use them and therefore not to activate anything;
- A gamification aspect will also be presented, whose aim will be enhancing users' experience by motivating them to use the new functions and, by association, public transport; a dedicated section of the app's menu will be present for this new aspect.

Push notifications and pop-up windows will be the tools used to convey information to the user about the journeys, validations, and gamification dynamics. Through these the user will be updated with information about the trip, the automatic check-ins and check-outs, and the game goals achieved, and above all information will also be provided about the correct operation of the system.

The new gamification functionalities will contemplate an update on the account manager, currently only used for billing information, to allow for more personal information

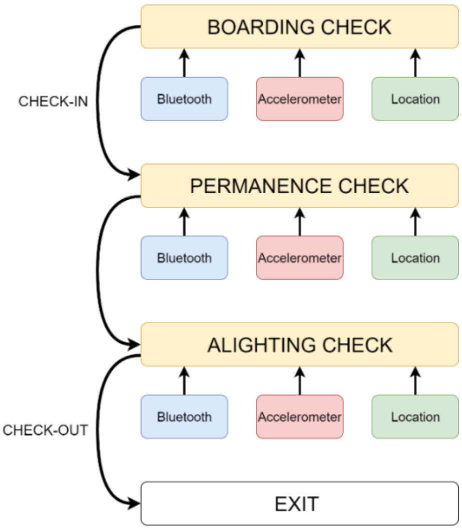

Fig. 2. Main structure of the automatic process' checks

to be input, and for the creation and customization of a personal avatar. A major incentive to use this new system will be a scoring system, where points will be awarded to each user after a complete check-in / check-out cycle, regardless of the method they used to perform these actions. This way, even those users who choose to continue using QR codes can be persuaded to perform more check-outs before alighting. The points earned will allow users to earn cosmetic prizes, namely badges or accessories to decorate their avatar. They will also be able to compete with other PT users, either by sending/accepting direct challenges (e.g. the most points earned in a week) or by climbing the global points rankings. To this end, the new gamification section will have a dashboard, where users will be able to see their avatar, and to find all the badges they obtained, the challenges, both ongoing and past, and the global rankings.

At least in the first phases of the experimentation, the automated check-in process will be reserved for a subset of users only, probably only those who own a monthly/annual bus pass. The remaining users will still use QR codes for the check-in phase, while the subsequent steps will be the same for all users. The automatic validation functionality will be switched on from the screen of the selected ticket, then it will remain active for all following uses of the ticket until the user chooses to turn the function off or the ticket expires.

E. System Prototype

For the time being, a demo app developed for iOS with Swift programming language is available. The primary objective of this app is to collect and store data from all smartphone sensors which are going to be used in the final version, *i.e.* Bluetooth, accelerometer, GPS, and camera (for QR codes).

After asking the user to consent to the use of the services, by means of dedicated pop-up windows, data recording is turned on or off based on the tests to be performed. Every *R* seconds (this value will also be optimised after the tests, to minimize the amount of data exchanged from the smartphone) a certain set of information coming from the smartphone is recorded following a data structure, which includes:

- the user coordinates (latitude and longitude);
- the physical activity performed by the user;

- the bus's identification code (from the QRcode);
- the relevant timestamp;
- the list of all nearby beacons detected by the smartphone (at first, this datum will be recorded every second, with the corresponding timestamp).

The preliminary test phase was dedicated to testing sensor operations and stability, recording raw data and then analysing the patterns identifiable in the multi-sensor data flow. These patterns should in some way correspond to the events needed to achieve the automated process of ticket validation on the bus, namely check-in when boarding and check-out when alighting. By recording automated data and "real" events (*i.e.* check-in and check-out via QRcode) at the same time, the patterns can be labelled by comparing the timestamps of the two sets of information.

The app, while in foreground, records data on a dedicated structure, which is then exported to a text file for subsequent processing. After a complete test, the text file is sent via e-mail to an account where all the data can be stored. The layout is such that the proper functioning can be verified by the tester very easily, by visualising on a single screen all the real-time feeds coming from the sensors involved. It is basically a tabbed app, with 4 separate tabs for:

- QR-code, where the live data stream is shown and whose controller is responsible for recording;
- Beacons, which show the currently recognisable beacons and allows to add new ones;
- Monitoring, where the beacon regions monitoring can be turned on / off, triggering "enter" or "exit" events (a region is defined by beacons' UUID);
- Ranging, in which the function to detect the beacons' proximity () and accuracy () can be turned on / off.

The Major and Minor values of the beacons are those which will be effectively used to differentiate them and when evaluating the "distance" between smartphone and bus.

IV. TESTING

In this section we present the results achieved when evaluating the performance of the proposed system using the BLE beaconing technologies. At first we describe the test setting and then we present the results.

A. *Test setting*

The first batch of tests was performed with the developed prototype installed on both an iPhone and an iPod, and it focused on analysing the accuracy in the detection of all the phases of ticket usage. For all the tests, the *R* parameter (i.e., the frequency at which the smartphone performs the monitoring and the processing operations) was set to 5 seconds. These tests can be split into three categories:

- **Approaching beacons placed in an indoor setting -** the beacons were placed on a corridor, inside a rectangular region simulating the shape and size of a bus; starting from far beyond the beacons' range, the testers approached the "fake-bus" with the demo app active and in recording mode; they then entered the "fake-bus" and used a QR code to perform a check-in; after a few minutes, they used the same QR code a second time to perform a check-out, they left the "fake-bus", and finally moved away from the beacons, leaving their broadcasting range;
- **Detecting beacons while riding on a bus -** this test was necessary to collect data in a situation as close as possible to that in which the beacons will operate, when the system becomes fully operational. Since installing beacons on the vehicles was not yet possible, it was decided to operate independently from the service operator, by manually bringing the beacons on board for each test. This means the testing team needed one app tester, and three "beacon carriers", who held on to the beacon the whole time. The team coordinated to follow a precise scheme, which started when the "beacon carriers" boarded a bus at a designated bus stop and arranged themselves in different positions (front, rear and centre) on the bus; the app tester was waiting at the next bus stop, with the app ready and recording, and boarded the same bus. He then proceeded to check-in with the bus's QR code (if possible he stood in a central position on the bus). The app tester then got off the bus after one or two stops after checking-out with the QRcode, while the "beacon carriers" stayed on, and got off at the next stop.
- **Waiting at a bus stop -** with the same settings as the previous test, but this time the tester did not board the bus where the beacons were "installed", but simply waited at the bus stop for the bus to pass, while registering with the app, and scanning a specific QR code when the bus arrived at the stop; this was necessary to determine what happens when a user is waiting at the bus stop, but one or more beacon-equipped buses pass by before the one he wants to ride arrives.

Each of these tests was repeated 5 times, from start to finish using three beacons each time. The previous tests consider the system's operation under optimal circumstances in a controlled environment, meaning the only beacons in range were those of a single bus, that is the one the user intends to board. To test a more "stressful" system configuration, another batch of tests was performed. In this case, two cars represented two "fake-buses", each equipped with a set of three beacons and two different QR codes, and the following tests were performed:

- **Detecting beacons placed on two different buses -** the user is riding a bus equipped with beacons (bus A) while, close by, another bus (bus B) is traveling at a very short distance with its own beacons; in this case the app should be able to understand that the A beacons are closer than the B ones, since the signals received from bus B are supposedly weaker, and this should be reflected by the data recorded by the demo app. The tests took place in a large, almost empty parking area, were it was possible to keep a constant distance between the two cars, and to test the different relative positions of the "fake-buses", *i.e.* A in the front, B in the front or side by side. After; the initial check-in, each tester remained in one of the cars, and registered the relative position of the vehicles (back or side) by scanning a different QR code each time one of the two cars changed position. And finally at the end of the trip for the check-out;

- **Waiting at a bus stop where a bus is idle -** to simulate what usually can happen at a bus terminal where several bus lines converge, and it is not unusual to find many vehicles idle close to each other. One of the cars stayed at the "fake-bus stop" as did the testers, using the app to record data; the other car approached from a position out of range, then stopped at the "fake-bus stop" and the testers boarded and checked-in; the "fake-bus" made a short trip, then returned close to the other car, waited for the testers to check-out and to get off, and moved off once again;
- **Switching bus -** this test was performed to define if the system was able to behave correctly when a user alights at a bus stop and immediately boards another bus positioned in front/behind the previous one. To simplify the tests, and since the beacons' data is not influenced by the status of the vehicle, the test was performed with the two cars parked one behind the other. Each tester approached the cars while recording with the app, got into one of them, checked in using the QR, and after a few minutes checked out, switched positions with the other tester, and repeated the same procedure in the other car, to finally alight and walk far away to stop recording**.**

B. Test Results

Figures 3 to 7 show the most representative results from each of the tests described above.

Switching bus - Fig. 3 shows the received power values "Bus1" and "Bus2", along with some crucial events detection. The first red vertical line represents the first "enter event" in a beacon region. There is a short time interval (in yellow, called "waiting") in which the trend of the received power from both sets of beacons starts from around -95dBm, then tends to increase, since the tester was approaching the two cars. Immediately after, the received power values tend to split, indicating the tester boarded Bus2 (the first green line, *i.e.* the manual check-in on Bus2), and representing two separate trends, one averaging -70dBm (for Bus2, the one boarded) and the other averaging -95dBm (for Bus1, the more distant bus). When the tester alighted from Bus2 (second green vertical line, *i.e.* check-out Bus2) and boarded Bus1 (first purple vertical line, *i.e.* check-in Bus1), the two trends and their average values reversed. In this phase, the average received power was -93dBm for Bus2's beacons and -67dBm for Bus1's beacons, up to the second vertical purple line (check-out Bus1). At the end, the two points tracks both drop towards -95dBm, corresponding to the user exiting from Bus1 and walking away from both vehicles. The last vertical red line identifies the instant of the exit event from all beacon's regions. Since this test was carried out without the cars moving, no accelerometer related data is shown on the graph.

Waiting at a bus stop where a bus is idle - Fig. 4 shows experimental data from these tests. The first red vertical line indicates the enter event in the region defined by Bus1's beacons, whose received power values remain mostly below -80dBm. When Bus2 arrives, the received power is initially at the same levels as Bus1's beacons, but immediately after the tester starts the trip on Bus2 (first vertical green line, *i.e.* check-in Bus 2), the received power from its beacons settles around an average value of -73dBm. The power values from Bus1's beacons drop again after the event represented by the second green vertical line (*i.e.* check-out Bus2), and even more thereafter Bus2 leaves the "bus-stop", to eventually become non-existent when Bus2 leaves the range of the smartphone. At the same time, since Bus1 stayed at the bus stop, the received power from its beacon rises, but presents the same pattern as before Bus1's check-in, with most values remaining below -80dBm. No more values are recorded after the exit event (last vertical red line). The grey horizontal bars represent the "activities" which the algorithm identifies by processing raw accelerometer data, using a numerical scale where 1 corresponds to "saying still", 2 to "walking" and 3 to "riding on a motorized vehicle". In the first part, between enter and Bus1's check-in, the activity is mostly "walking" (=2), as it should be. However, during the bus ride, probably because the car did not reach a high enough speed (for safety measures) and the trip was very short, "vehicle" (=3) is only reported in the last half.

Detecting beacons placed on two different buses - Fig. 5 shows the power values from the sets of beacons positioned in the two cars. The orange dots (beacons on Bus2) show a stable trend for the whole trip, with an average value around -67dBm, while the blue ones (beacons on Bus1) show an initially stable trend (Bus1 travels behind Bus2), then it starts to somewhat oscillate.

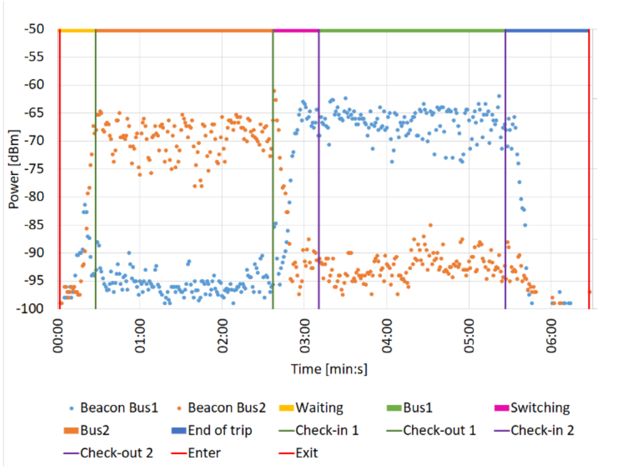

Fig.3. Results for "Switching bus"

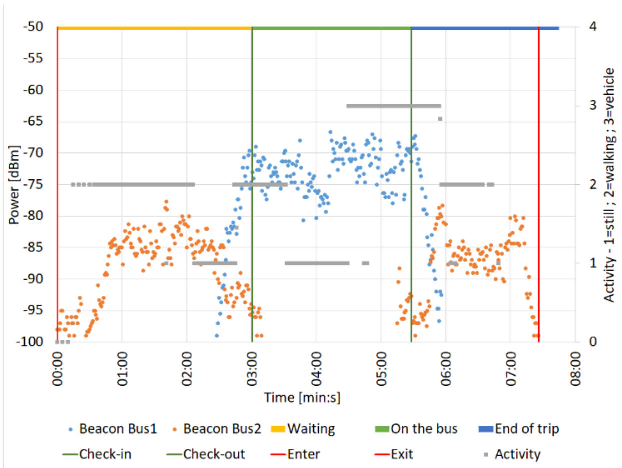

Fig.4. Results for "Waiting at a bus stop where a bus is idle"

This phenomenon is related to the change in position of Bus1 from behind Bus2 to its side, which corresponds to a slight increase in the received values of power emitted by the beacons placed on Bus1. Nonetheless, the trend of the values of Bus1's beacons still shows an average value of about -90dBm, much lower than the power received from the beacons on Bus2 (average value of -67dBm). The green bars indicate once again the exact time in which manual check-in and check-out actions were performed. The horizontal grey activity bars indicate that, for most of the trip, the detection placed the smartphone on a "vehicle" (=3).

Waiting at a bus stop - The few points shown in Fig. 6 represent the detected power values emitted by the 3 beacons on the bus, which was passing close to the tester at a bus stop. In this case the green vertical line corresponds to the instant when the bus stopped, but it can be immediately observed how the power never exceeds -85dBm, even when the doors of the bus are open and the user is close enough to them (less than one meter). In this case too, since the testers did not move from the bus stop, no data from the activity detection is represented in the graph.

Detecting beacons while riding on a bus - Fig. 7 shows the power values of the 3 beacons placed on a bus. Immediately after the first red vertical line (*i.e.* enter event in the region of the first detected beacon), power values start to be detected, with an average value of -80dBm, (even if there are fluctuations corresponding to the user moving inside the bus). In this case, the test conditions were more realistic, since the beacons were more distant from each other and the bus was quite crowded, with the exception that the beacons were held by the operators, instead of being mounted on the roof of the bus, as will be the case in the final system. It is to be expected that the power values detected will be significantly higher on the final installation compared to the average ones recorded in these tests, and therefore closer to those detected in the experiments with the beacons placed in the two cars. The activity between the check-in and check-out events (the two green vertical bars), as shown by the grey horizontal bar, is mostly "vehicle" (=3).

V. FUTURE RESEARCH

The work presented here is still in progress, and it will be developed further over the next few months. The first issue to be addressed is that of developing the Android counterpart of the iOS app, to allow for more people to test it. More testing will then be necessary, to check if the Android app works as well as the iOS one, and to conduct more in-depth tests on both versions. When the app is considered sufficiently reliable, an open test will be performed, involving a sample of real passengers. This way the stability of the system will be tested under greater stress conditions, since it will have to process a greater amount of data coming from different points and devices. Initially, the beacons will be installed only on few selected bus lines, chosen on the basis of different requirements. This configuration will allow, on the one hand, to install only a limited number of beacons, saving both time and money, while on the other it will be possible to test the system in two different situations: the first, in which BLE beacons can be detected by the smartphone, and the second, in which the app will have to rely solely on location and accelerometer data.

The gamification segment of the app will have to be developed completely, both in terms of coding, assuring all the functions work properly, and graphic design This aspect in particular is very important, since its successful implementation is basic to ensuring that the interface results are captivating enough for users to be happy to use it, and will continue to use all of the app's functions every time they need to travel on PT.

Fig.5. Results for "Detecting beacons placed on two different buses"

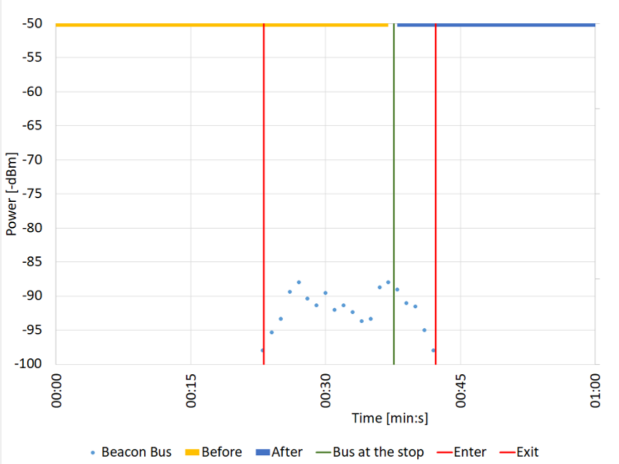

Fig.6. Results for "Waiting at a bus stop"

Fig.7. Results for "Detecting beacons while riding on a bus"

VI. CONCLUSIONS

The aim of this work was to develop an innovative application for automating the process of ticket validation on public transport. The system developed uses many of the hardware devices installed on modern smartphones, that is

- the camera, to read QR codes on the buses;
- Bluetooth, to receive signals from BLE beacons, which will be installed on the buses;
- location services, to identify users' position and compare it to the closest bus;
- accelerometer, to detect how the users are moving, in particular if they are in a vehicle.

The prototype can already use all the data coming from these devices, but it is still not complete and so cannot be released for public use. Moreover, in-depth testing is necessary before the entire automatic process can be definitely declared fail-proof.

The results from the data received by the BLE beacons are very promising, since the power of the signal shows very distinct patterns when a user enters a vehicle equipped with beacons, as opposed to when he is not inside it. However, in the event that beacons cannot be installed on all the selected buses, the other systems will have to be working as well as Bluetooth does. That is why activity recognition and location require further testing: the former because it may require fine tuning and the identification of clearer patterns; the latter because bus position data will need to be used, and this is still not possible as no agreement has yet been reached with the local public transport operators.

The work will certainly continue in this direction, with the completion of all the features of the iOS app and the development of the Android counterpart, so it can be publicly released, at least to a small group of users to increase the test sample. More importantly, the gamification will also be implemented, to verify to what extent it can help in persuading users to use the new app's features. All partner companies will be involved in the testing process, and BLE beacons will be installed on as many vehicles as possible. At the same time, an advertising campaign will be put in place to inform all users about the new app and its functions, hopefully to persuade even users who still now prefer traditional ticketing methods to "convert" to mobile ticketing.

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