A multi-service IoT platform for smart mobility - the case of an university school

Teresa Vazão, Pedro Antunes
INESC-ID/Instituto Superior Técnico/Universidade de Lisboa
Av. Cavaco Silva, Taguspark, Oeiras, Portugal
Email: {teresa.vazao, pedro.david.saraiva.antunes}@tecnico.ulisboa.pt

Abstract—Internet of Things is seen as a technology that can revolutionise traditional transportation and logistic businesses. The possibility of sensing and communication with vehicle in real-time extends the way traditional services are being offered and enable also new services. This work proposes a multi-service platform aimed to solve the mobility problems of an university community. The proposed system enhances the existing transportation private fleet service by providing online booking, authentication and real-time information services. These services rely on the use of different access technologies to guarantee real-time communication, location services to inform users about the position of the bus and readers to authenticate the users. The paper describes the services and platform architecture. An extensive studied of the embedded system component is provided, starting at the architectural design options, selection and testing of components. Tests were realised on a operational environment and cover a broad range of topics, such as technologies, services and users’ behaviours.

Index Terms—Smart-mobility, IoT, online booking, e-ticketing, location services, fleet management, embedded system.

I. INTRODUCTION

Modern society is confronted today with an unprecedented challenges, created by the need of achieving a sustainable development under an enormous social-economical pressure. This situation, triggered by the industrial development and population concentration in large urban centres, have become more critical in the past few years. Citizens and policy-makers are more than ever aware of the importance of preserving the environment, demanding new technical solutions and policies to monitor and control the usage of natural resources.

From all the existing problems, one of the most critical one that urges to be solved is mobility. Not only because transportation system has a significant impact on the environment conditions, accounting for 26% of global CO2 emissions and is one of the few industrial sectors where emissions are still growing [1], but also due to the economical and social impact of accidents and time travel. In fact, despite the introduction of many instruments in the transport system, they failed to reach their target since gains in global environmental efficiency have not been enough to cope with the consequences of transport growth [2]. A major concern in this topic is how to adequate the capacity of the transportation systems to the user needs in order to reduce consumption and avoid traffic jams.

In the meanwhile, Internet experienced a tremendous growth: advanced smart-phones with sensing and location capabilities and other hand-held devices are widely used, broadband wireless technologies, such as WiFi and 3G, are widespread and different cloud-service providers offer storage and more advanced computing services [3]. On other hand, people are more than ever engaged with technology, actively contributing with their own contents to the so called Web2.0. The existence of such volume of information available contributes to important cultural changes and, nowadays, citizens are much more aware of their role in society, willing to participate and contribute to the community, as can be easily stated by the statistics provided by the International Telecommunication Union (ITU) about the rise of social networks[4].

More recently, the advances in embedded systems lead to the existence of very diverse, easy to use and low-cost micro-computers and controllers, where a huge range of peripherals, sensors, actuators and communication technologies may be easily integrated. When interacting with the physical world, these smart objects can retrieve meaningful information from the surroundings transmitted.

All these technologies are the basis of the so called Internet of Things (IoT), which will be the major revolution in the Information and Communication Technology (IC) domains. Unquestionably, IoT will have a major impact in everyday-life, modifying existing industries and creating new ones, but also affecting the behavior of potential users [7]. IoT will represent a huge opportunity in many different areas, such as like home-automation, health-care, mobility or entertainment, but due to the enormous complexity and scale of this new type of network the challenges are huge [5]. Different architectural models have been presented so far aimed to deal with the specificities of these networks [6].

In the mobility area, IoT can revolutionise traditional transportation and logistic businesses. The possibility of using bar codes, Radio Frequency Identifiers (RFID) tags or sensors with embedded communication capabilities creates the possibility of real-time monitoring of goods, vehicles and passengers, from an origin to a destination, leading for significant improvements in the mobility process. In fact, in recent years, different studies have shown the application of IoT to specific areas of mobility, such as logistics [8], assisted driving [9], mobile ticketing [10], [11] traffic management [12], [13] among others.

In the specific niche of mobility, the emergence of Vehicular Ad-Hoc Network (VANET), where vehicles may communicate among each other or with infrastructure elements along the road through a dedicated technology, represents a huge op-
portunity to improve Intelligent Transportation System (ITS) and its applications. Nowadays, Vehicular Adhoc Network (VANET) had captured the attention of many and very diverse players: research community, standardisation bodies from transport and networking areas, policy-makers, manufacturers, road operators, fleet transportation and software companies, among others [14], [15]. Nevertheless, the challenges are huge due to the lack off-the-shelve available technology that is needed to setup the network. While VANET technology is not mature enough, cloud computing vehicular networks appears as an emerging trend [16], [17].

This paper presents a cloud-based vehicular network IoT platform - TagusShuttleBus - that provides a new approach to the mobility problems faced by an university community to reach one of its the campus facilities. Currently, the school offers a private shuttle system, with hourly services from both directions, that can not be changed, using buses with fixed capacity. In spite of the number of trips available, the service fails to meet the community expectations because when it is most needed there is no guarantee of available seats and users may need to find alternative solutions just-in-time. On the other hand, the school incurs unnecessary costs due to existence of a significant number of trips with few passengers. Besides this, the use of such large buses almost empties represents a waste of energy and the school is aware of the importance for students social education of its own contribution to sustainability.

This paper is organised as follows: section II describes the platform, including the services provided and the architecture. After that, section III presents the platform design, with a particular emphasis on the component embedded into the bus. After that, section IV presents the test scenario and results achieved. Finally, section V concludes the work and defines its future directions.

II. PLATFORM DESCRIPTION

A. Mobility Services

The TagusShuttleBus is a multi-service platform that supports school members and administration mobility through a set of services. These services are organised into three main groups: shuttle services, information services and management services.

1) Shuttle services: The shuttle services are responsible for all the tasks associated with the shuttle transportation service. The shuttle configuration is used by the staff to configure the characteristics of the shuttle transportation service, as well as the school policies regarding booking and capacity management. Regarding the configuration of the transportation service, routes, schedules and buses capacities are defined. The school policies define the number of seats available for booking and, in case of a shared mobility agreement, the number of seats available for that agreement in each route.

The services are also used by members of the school to perform online booking. Members of the community may do this for their own use and the staff may do it on behalf of authorised guests.

Other services, such as access control and booking validation, are provided to support the business activities related with the transport of passengers in buses. Access control is used to guarantee that only members of the community, authorised guests or members of partners institutions may use the service. Booking validation is used to monitor users’ behaviour regarding their bookings and to act according to their behaviour is future reservations requests. Well-behaved users should be rewarded and mis-behaved users should be penalised.

2) Information services: The information services are used to provide any type of information, gathered from the buses or transmitted to them, that might be related somehow with mobility.

Through information services users have real-time access to location and occupancy of in transit buses. Hence, they may be informed about service delays and, if they did not book any seat, decide if and where they should enter the bus. The staff can use the same information to analyse the transportation service performance and change its characteristics, if needed.

Transmission to geo-referenced information to passengers may also be possible.

3) Administration services: Finally, administration services are used by the staff to manage the platform, register authorised guests and setup general properties of shared agreements.

B. Platform architecture

This section describes the system components and interactions of the TagusShuttleBus platform.

1) System components: As depicted in figure 1, the TagusShuttleBus comprises three main systems: the Central Shuttle System (CSS), the Mobile Shuttle System (MSS) and the Shuttle On-Board-Unit (SOBU).

![Fig. 1: TagusShuttleBus platform architecture](image)

The platform uses a centralised network architecture. The CSS is the core component of the platform, being responsible for the coordination of all the services and for the information repository. It receives requests from the MSM or SOBU and respond to those requests. Its tasks include fleet management, booking coordination, users’ credit management, electronic ticketing generation, bus tracking and historical data management.
The MSS in an application that provides mobility services to the users. The MSS is accessible through the Internet, using any type of personal device and access technology. Users may access the online booking, shuttle configuration, mobility information or, in case of the staff, the administrative tasks.

Finally, the SOBU is an embedded system that provides support to mobility services in each bus. It is responsible for access control, booking validation and location and occupancy information retrieval. It interacts with the CSS via WiFi or, in case of network unavailability, by 3G. It also needs to access the GPS to retrieve location information.

2) Operational processes: The operation of the TagusShuttleBus can be divided into two operational processes: planning and travelling.

The planning process involves interactions between the MSS and the CSS. During this process users have the opportunity to reserve seats and the staff can adjust the bus capacity. In order to have a fair system, responses to booking requests must take into account the user behaviour when compared to other users that have also requested a seat on the same bus. Hence, the planning process is divided in four phases:

- **Booking opened** - where users can submit booking requests.
- **Booking closed** - where users can no longer submit booking requests and the staff is examining the number of requests issued to adjust the bus capacity, if needed.
- **Booking decision** - where users that requested a seat are ranked according to their credits to decide the ones that will have granted access and tickets are generated for the users with granted access.
- **Booking terminated** - where users are informed about the result of their request and, in case of having successful reservation, receive a ticket.

In the travelling process the SOBU interacts with the SCC, in real-time, since the beginning of the trip till the end. During this phase authorised users can access the bus. If they have a granted reservation they have a seat on the bus, but if they do not have they may try to find one (reserved and non-occupied yet), after all users with bookings have entered the bus. In order to guarantee that all the information that is needed to take these decisions, this process is split in four phases:

- **Travel record** - where the SOBU asks for and receives the list of reservations for the next trip.
- **Access control** - where the SOBU authenticates the users so that only authorised members can enter the bus and sends that information to the CSS for accountability purposes.
- **Location** - where the SOBU announces its location in order to allow users to find out the most adequate stop to enter the bus.
- **Travel info** - where, at the arrival at the destination, the SOBU dumps to the CSS the entire trip information for logging purposes.

III. PLATFORM DESIGN

Both CSS and MSS are typical software applications, that are hosted in the school data center, run Linux Operating System, are coded in Python, and the CSS server exposes a REST API to the MSS. No specific design options need to be taken into account and the tools, methodologies and programming frameworks available for web applications have been used.

Contrariwise, the designed of the SOBU was specifically tailored to this system and the vast majority of options have been taken considering the application use case. Hence, the rest of this section is devoted to the SOBU description.

A. SOBU design options

There were several aspects that were specially taken into account in the SOBU design: the access control, the need for real-time communication and the need for location information available.

1) Access control: The shuttle transportation system was created to support the school members, authorised guests or members of other institutions with whom the school has a shared agreement. The access control system must be designed to recognise the school identity cards, the Near Field Communication (NFC) smart-cards. However, as external users that do not have this card other sort of access control must be provided.

The option that was taken was to use an identity that might be easily carried, for instance in a smartphone or a piece of paper. Hence, the selection came into an electronic ticket with a QR-Code, using a solution similar the one used nowadays by airlines companies [18]. The ticket contains the user information and a timestamp so that it has a limited validity. To avoid plain text, a Secure Hash Algorithm (SHA)-256 is used to generate the QR-Code identifier. A ticket is depicted in figure 2.

![Fig. 2: Electronic ticket](image)

Whenever a passenger enters the bus, the SOBU must signal if the access control succeeds or not. The most simple, but yet effective solution, consists in using leds and buzzers to inform the passenger of the result of his authentication.

2) Communication: In order to keep the status of the SOBU up-to-date, it must be able to communicate in real-time with the SCC. This communication is twofold: first, sends access control data to compute occupancy and second, sends location data to know the bus position and route.
The access data is generated whenever a passenger enters the bus. The departure stop is usually located near one of the campus of the school, probably within the coverage area of the WiFi network, but, in the other stops along the route there is no WiFi unavailable and an alternative connection is needed. Hence, connection to the Global System for Mobile Communications/General Packet Radio Service (GSM/GPRS) network must also be provided to enable data transmission through the cellular network (3G).

3) Location: Having the position of the bus available in real-time allows user to find out the most convenient stop to enter in. The majority of the times, location is retrieved from the GPS system.

Registration on the GPS network requires the detection of a minimum of four satellites. Occasionally, this process consumes a significant amount of time or does not succeed at all. So, whenever the SOBU is not able to register into the GPS network, location information may be retrieved from the 3G networks.

Using the 3G network enable us to locate the position of the antenna to which the SOBU is connected. Although having a much smaller precision than the GPS [2], this information is enough to identify a particular bus stop, but not to calculate the route.

B. SOBU hardware

1) Microcontroller: The SOBU is a device to be installed on buses, which requires frequent handling by passengers in the access control component. This requires that the system is easy to install, but, at the sometime, is robust to withstand the shake of the trip and the most sudden accesses. Additionally, low cost, off-the-shelve components need to be used so that the system may be easily assembled and scale up to the number of bus needed, without representing a significant financial investment to the school.

In order to cope with these requirements, for the selection of the micro-controller, one of the aspects that was taken into consideration was the need to reduce the number of connections to peripheral devices. Besides making the device easier to assemble and more rugged, it also consumes less power which is an important aspect to consider in this type of systems. Hence, the main system is a Raspberry Pi2 single board computer.

2) Communication and location: WiFi connection may be easily provided through an USB WiFi adapter and one of the USB ports of the Raspberry Pi2. Regarding 3G network, none of the available modules may be directly attached to it. So, the option was selecting a 3G network shield that were developed for Arduino and adding an Arduino micro-controller to the SOBU. The select hardware was a TEL0051 module, from DFRobot [20] that enables access to GSM network and short messaging system (SMS).

Additionally, it also supports GPS technology for satellite navigation. Serial line communication is used through AT commands.

To connect the communication shield to the General Purpose Input/Output (GPIO) pins of the Raspberry Pi2 a bridge device, Arduberry, was also added.

3) Access Control: Regarding the access control devices, a smart-card reader with contact, contactless and NFC technology was used to read the school identity card. The selected equipment was an Identive Cloud 4700F, from Identive.

For the QR-Code reader the selected options was a DS9208, from Motorola that scans both 1-D images (barcodes) and 2-D images (QR-Codes). Both peripherals are plugged-in to the Raspberry Pi2 through USB interfaces.

4) Components assembly: Using the above components, the hardware structure of the SOBU is depicted in figure 3.

![Fig. 3: SOBU HW components](image-url)

C. SOBU software

1) Microcontroller: The SOBU uses the Raspbian OS, a Debian GNU/Linux version optimised for the Raspberry Pi hardware. It is programmed in Python and supports multitasking. The micro-controller is responsible for coordinating and scheduling all the tasks that are needed to support the services provided by the SOBU.

The first stage is the initialisation, where the communications and peripheral outputs are tested.

After that, the travel record is uploaded to the SOBU. In order to receive the adequate record, it starts by retrieving and sending to the SCC the bus location and time. In case of unsuccessful location, it is not possible to determine the travel record associated with that trip. Under this circumstances, the SOBU is still able to perform access control, but not booking validation.

After that, the SOBU is able to perform access control and location.

At the end of the trip, when the location is closer to the destination, the travel info, containing the complete route log, is dumped to the SCC.

2) Communication: In the available hardware, the GSM/GPRS connection is multiplexed with the GPS signal, meaning that no simultaneous access to the serial line can be made. In order to avoid conflicts, every time each one of the components, GSM/GPRS or GPS, want to access the bus, they need to realise a complete cycle.

Data transmission was considered the most priority and whenever there is access data in the transmission queue, the GPS is not able to access the serial bus. Initially, the WiFi network is checked and, in case being available, it is used. Otherwise, the SOBU initiates a new connection to the SCC, transmits the data and, at the end, terminates the connection.
3) Location: Whenever the transmission buffer is empty, the SOBU can retrieve location information. To do so, it register on the GPS network and, during two minutes, receives up to ten locations. These locations are stored in a local log and, the last one, transmitted to the SCC. At the end, the GPS is unregistered in order to free the serial line for use by the GSM/GPRS communication module.

Location through the 3G network is only used for the initial phase to receive the travel record. For the remaining cases, the values are so inaccurate that can not be used to identify the bus position while traveling, nor to reconstruct the route at the end.

4) Access Control: In order to have a fast detection, the access control is performed independently for each one of the readers. After reading the identifiers, there is a common task that validate them, warns the passengers and transmits the information to the SCC.

IV. RESULTS

The TagusShuttleBus platform were deployed in a bus and a set of experiments have been made from January to July 2016. Deploying and testing the system in a real operational scenario was a challenging task, due to the number of variables that impact the desired results. From the physical world operational conditions, users’ behaviours to the technical details, such as architectural design choices, selected components and technologies, and implementation, all affect the final result.

Instead of realising a set of laboratory tests, where a significant number of variables can not be assessed, an extensive set of operational tests were made. The next sections detail them.

A. Test scenario

The TagusShuttleBus platform began to be used in January 2016, on an experimental basis, mainly on trips that took place on Saturdays to transport the school members to the examinations or other special activities. Therefore, it was possible to run real tests without disrupting the daily activity of the school. For this, the SCC and MSS were installed in the school data center and the SOBU was deployed in the bus, which was being used in the shuttle transportation system. The SOBU was connected to the bus lighter via USB and placing near the front window, with the card-readers fixed in such position that passengers can easily access them without damaging or let them fall.

The system started by executing the planning process. Online booking requests opened at least two weeks before each trips and closes the day before, at 2 p.m. At 4 p.m. users that requested online booking received the result of their request. In the meanwhile, the staff had the opportunity to adjust the bus capacity or just drop the trip, in case of an insufficient number of users.

For the direct trip (direction 1), the bus departed at 8:00 a.m. from the school main campus, had an intermediate stop in a transport hub of Lisbon and terminated at the other campus of the school. By lunch time, the bus returns to the main campus, through the reverse path (direction 2). At the main campus, as the bus stop is located outside the campus premises, WiFi was not always available.

All the steps of the travelling process were realised. Before starting the trip the OBUs was initiated and, when it started incoming passengers used access control system at the entrance of the bus to authenticate themselves, using the school identity card or the QR-Code. During the trip, bus occupancy and location information were transmitted to the CSS. Near the destination, a dump of the local log to the CSS was made.

There was a member of the project participating in all the trips with the responsibility of registering information that can not be captured by the system but might be important to support the analysis of the results, such as number of passengers and number of owners of school identity card or QR-Code, users behaviour, among others.

Figure 4 depicts a picture of the system in one of the operational tests.

B. Technology test

Technology tests were used to assess the different technological components. In the following sections the scenario and the tests that have been realised are presented.

1) Test scenario and goals: As stated before, all the tests were made in real operational conditions. For this particular set of tests, the information was logged into a unique repository, that hidden the detail about the trips, since the goal is to evaluate how the different technologies performs, in a overall perspective. The analysis were mainly focused on the SOBU, which is the key element to improve the mobility experience.

2) Communication technologies - 3G and WiFi: The first set of tests evaluates the performance of the communication technologies.

Registration in the GSM network is needed to start using 3G, which an important step of the system bootstrap. Figure 5 depicts the time needed to register the SOBU into the network, using an histogram representation.

The analysis of the results show that, usually registration into the network requires less the 5 seconds, but, sometimes more time is needed or registration fails to succeed. The order of magnitude of registration delay is within the acceptable limits, since the bus arrives at the departure stop around 10 minutes before the time scheduled and the registration in GSM network executed only once, when the SOBU is powered up. However, being unable to register into the network means that, during the travel, real-time communication is not possible.
Therefore, the SOBU must rely in local access control and log dumping at the arrival stop through WiFi.

![Fig. 5: Registration time distribution: 3G/GSM network](image)

When the SOBU is turned on, the operating system activate the WiFi network and so the SOBU does not need to enforce registration in this network. Hence, the next set of tests compare the two access technologies and the impact of their usage in the users experience.

For this, the metric chosen is the **response time**, which represents the elapsed time since the SOBU sends a request til it receives a response.

Figure 6 depicts the cumulative distribution function (CDF) of the response time. The results shown that WiFi has a significantly better performance than 3G. In WiFi, more than 80% of the requests are answered in less than 0.2s and the highest value is about 10s. In 3G, about 80% of interactions require more than 20s and the highest value is around 200s. Although users experience a noticeable response time when using 3G, the fact that will have access to information that otherwise was unavailable, pays off the delay in getting the answer.

![Fig. 6: Response time CDF: 3G and WiFi networks](image)

3) Location - GPS: The second set of tests evaluates the GPS location system.

Figure 8 represents the time needed by the SOBU to acquire the GPS signal. The registration time in GPS network ranges from about 20 seconds and more than 80, being the most probable value around 60 seconds. These values can be justified by the need to find a minimum number of satellites to determine the SOBU position.

There were a few cases where registration in the GPS network fail to success and the SOBU must rely on the information provided by the 3G network to determine the node’s area (as an exact position can not be obtained in this case).

![Fig. 8: Registration time in the GPS network distribution](image)
Figure 9 illustrates the route obtained by the location system, with a sampling interval of 20s, 10s or 5s. The results showed that GPS provides a fairly good precision even with a higher sampling interval.

4) Readers - NFC and QR-Code: The third set of test evaluates the NFC and QR-code technologies and the readers equipment that have been selected.

To compare the two technologies two different metrics have been used: the delay of the authentication process and the success rate.

Figure 10 depicts the CDF of the authentication delay and figure 11 depicts the success rate. NFC technology outperforms QR-code by having smaller delay values. Nevertheless, the difference is not significant, as these are values in the order of milliseconds. Regarding authentication success rate, QR-code is much better, as no unsuccessful authentications have been registered. In case of NFC, unsuccessful authentications might be justified by an invalid smartcard or a by a mishandling of the card during the authentication process.

C. System test

System tests were used to assess the behaviour of the system in terms of the services offered to the users. In the next sections the scenario and the tests that have been realised are described.

1) Test scenario and goals: From all of trips that were realised, a subset of three two-way trips have been selected that illustrates different operational conditions, according to the information described in table I.

The member of the team that participated in these trips reported that there were no entrances on the intermediate stops. These trips occurred on Saturday and there are a lot of free parking spots available in the nearby of the school main campus. Hence, all passengers entered in the departure stop and left it, in the return trip, at the same place.

<table>
<thead>
<tr>
<th>Trip date</th>
<th>Direction</th>
<th>WiFi</th>
<th>3G</th>
</tr>
</thead>
<tbody>
<tr>
<td>4th, June</td>
<td>Direct (1) Return (2)</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>11th, June</td>
<td>Direct (1) Return (2)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>18th, June</td>
<td>Direct (1) Return (2)</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

2) Service test: During the travelling process the SOBU interacts with the SCC to offer services to the users. An interesting aspect to evaluate is to what extent these configuration of access technologies affects the different services offered by the SOBU. Hence, a first set of tests was designed to evaluate this.

The travelling operation process comprises four different phases that are deeply related with the services offered by the SOBU. The travel record supports the booking validation shuttle service; the access control supports the users’ authentication for the access control shuttle service and for the occupancy information service; the location supports the location information service; and finally, the travel info consolidates route information needed for the shuttle configuration shuttle service.

So, to measure the impact of communications on each service, we start by analysing the transactions (request-response) that were registered in each phase for each one of the trips. The results are depicted in table II.
The analysis of the table shows that, travel record has successfully downloaded the list of reservations in all trips, using either WiFi or 3G and so the booking validation shuttle service has all the information it needs to operate.

Regarding the access control phase, passengers were able to authenticate themselves, using the same technology that was used in the previous phase. A single exception was registered in trip 3, where one of the accesses, near the main campus, used WiFi technology as the bus was passing in the nearby of a campus building. Therefore, both access control and occupancy services can be provided.

Apart from direct trip 1 and return trip 3, location service used a mix of technologies, which is expectable since WiFi is only available in the vicinities of the second campus of the school and GSM is used near the main campus and during the route. Therefore, as no GSM connection was available in return trip 3, no location information can be provided while the bus is travelling. All the records were registered when the bus is waiting for departure or, in movement, but still near the campus. This means that, location service was affected by the fact that the SOBU was not able to register into the GSM network.

Finally, travel info was only uploaded in the return trips, as it was not possible to do it through the WiFi network. So, at the end of the travel, there was information missing about the routes that might be useful to plan future services.

### TABLE II: Transactions per phase per trip

<table>
<thead>
<tr>
<th>Phase</th>
<th>Trips</th>
<th>Direction 1</th>
<th></th>
<th>Direction 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>2G</td>
<td>WiFi</td>
<td>Total</td>
</tr>
<tr>
<td>Travel record</td>
<td>4, June</td>
<td>1 1 0</td>
<td>1 0 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11, June</td>
<td>1 1 0</td>
<td>1 0 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18, June</td>
<td>1 1 0</td>
<td>1 0 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11, June</td>
<td>11 11 0</td>
<td>4 0 4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Access control</td>
<td>11, June</td>
<td>20 20 0</td>
<td>19 0 19</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18, June</td>
<td>19 18 1</td>
<td>10 0 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4, June</td>
<td>32 32 0</td>
<td>35 19 16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>11, June</td>
<td>27 25 2</td>
<td>21 13 8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18, June</td>
<td>24 22 2</td>
<td>37 0 37</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4, June</td>
<td>0 0 0</td>
<td>1 1 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11, June</td>
<td>0 0 0</td>
<td>1 1 0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18, June</td>
<td>0 0 0</td>
<td>0 0 0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Another important aspect to analyse is the impact of each one the phases in the communication between the SOBU and SCC. For this, the volume of data that is generated in each phase is measured. The results are depicted in figure 12. A first analysis of the figure shows that, the travel info consumes significantly more resources than the others, as a complete dump of the local log is transferred to the SCC. access control and location phases consume around 2kB and 5kB, respectively, which are still small values when compared to the 51kB of the travel info. Although the exact values depend on the number of passengers and positions gathered, respectively, the order of magnitude is very small.

Therefore, the communication architecture was properly designed to support the services and the volume of data generated is acceptable. From a financial perspective, this means that communications costs will not be a bottleneck for the system deployment.

D. Users behaviour test

Users behaviour tests were used to assess how users perceived the system and deal with it. In the following sections the scenario and the tests that have been realised are presented.

1) Test scenario and goals: For this test, the entire set of trips have been used in order to have a larger dataset. The aim of this test is to assess whether or not users are able to cope with the booking and access control policies that will be enforced, by the school.

2) Planning phase: The final tests aims at assess how users perceive the services, regarding the access control and online booking. Figure 13 depicts the statistics of the service usage during the operational test. The analysis of the booking results shows that, it was always possible to meet the service demand, as all the requests had been satisfied. This is mainly due by the fact that, there is a small number of students that need to go to the school for the examinations when compared to a normal day in the school.

Regarding the users behaviour, a significant number of passengers accessed the bus without a valid ticket or identity card, and, some of the reservations were not validated. As this was a testing phase, used also for diagnosis purposes, no enforcement was made by the school to force an adequate behaviour.

Therefore, users that do not have a valid school identity card or QR-code were allowed to enter the bus. Additionally, rewarding/penalty policy was also not felt as a need, since there are plenty of seats available and users that are not allowed to book a seat, due an invalidating booking, can still enter the bus as passengers without bookings.

Should the service become fully operational, the school must inform the community members about the service policies.

V. Conclusions

This paper presents the TagusShuttleBus, which is a platform that provides a new approach to the mobility problems faced by an university community to reach one of its the campus facilities. The platform provides a set of mobility services that allow users to perform online booking, authentication.
at each bus and getting information in real-time about bus occupancy and location.

The platform comprises three systems: a central entity (SCC), a mobile node (MSS) and an embedded system (SOBU). It was completely implemented and tested in a real operational scenario during more several months. The components and technologies selected have been extensively tested and proved to be adequate for the purpose of the system.

Regarding the services, the results achieved showed that authentication and online booking as expected, but location service fails to deliver information to the users, in real-time, whenever there are problems in the 3G network.

Although more than 50% of the users cooperated with the system and behaved according to the expectations, non-authorised passengers and non-validated bookings have been detected. Hence, a additional effort is needed to inform the users about the service and policies, before installing it.

We intend to install the system for daily operation and find out if the reward/penalty policy is enough to get the users cooperation. We also intend to extend the deployment of the system to other entities that owns a private fleet so that a real shared service will be provided with benefits to all partner institutions and members.

From technical perspective, we plan to extend this platform to other services and to provide a direct communication with the SMM and the SOBU.

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Pedro Antunes is a Master student of Telecommunications and Informatics, at Instituto Superior Tecnico, from the University of Lisbon. He is also a junior researcher at INESC-ID. His research interests are focused on Intelligent Transportation System. He is currently responsible for the mobility platform of IST.