The Charge Collector System

A New NFC and Smartphone-based Toll Collection System

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***Abstract* — This paper proposes a new system to collect tolls on open road tolling (ORT) infrastructures. The actual Electronic Toll Collection (ETC) systems do not fulfill fundamental user requirements, such as interoperability and portability between systems and road operators (in the same or different countries), as well as advanced toll logging and reporting (capabilities ensuring user privacy, an interesting feature in car rental or sharing use cases). The C2S is a work in progress project that will provide some features, such as flexible payment options, recording of incurred tolls and make them available to the end user and management entities, exploring a synergy of technologies in ETC scenario, namely Dedicated Short Range Communication (DSRC), Global Navigation Satellite System (GNSS), Near Field Communication (NFC) and smartphone-based mobile applications. This system is also an approach to interoperable European ETC solutions, in a way that uses DSRC and GNSS-based solutions together.**

Keywords— Electronic toll collection; EETS; DSRC; GNSS; multitechnology OBU.

I. Introduction

Since the 60's, the Electronic Toll Collection (ETC) is used around the world and, on last decade, it is becoming more and more pervasive [1]. The benefits of ETC associated to free flow systems are well known and the actual trends point to the creation of Open Road Tolling (ORT) infrastructures, i.e., roads where tolls are entirely electronic with little or no impact on traffic flow. The two main technologies used on ORT are based on:

- Dedicated Short Range Communication (DSRC) transponders [2], using 5.8 GHz microwave technology;
- Global Navigation Satellite System (GNSS) with Global System for Mobile Communications (GSM) [3], i.e., satellite positioning coupled with mobile communications.

Besides its advantages, the current ORT systems do not address conveniently the following issues:

- The flexibility of the bank account that can be used for toll payment, i.e., currently, users have always to pay by the same bank account, which can be an issue in some cases;
- The payment information/receipts or toll logs are not readily available to the user or management entities. In some cases, such as rent-a-car or car sharing companies, there is a need to know if costumers used tolls and payment has been done. In some systems, the information or toll receipt takes 48 hours to be available [4];
- The lack of an On-Board Unit (OBU) user interface that could provide road information and support for implementing Dynamic Road User Charging (DRUC) [5] systems. On current systems it is impossible to apply different prices on several users in real-time because there is no user interface to say how much he/she has to pay [6];
- The problems related to interoperability between different systems. If a user travels abroad, she/he cannot use ETC automatically without buying the local OBU [7];
- In case of GNSS-GSM based infrastructures, the toll companies have to use GSM so they are dependent of mobile operators [8].

These issues constitute a set of challenges that motivate the researching on new technologies and tolling mechanisms.

This paper starts with the motivation to this work, i.e., what is the problem that this solution solves. Next, the architecture and the utilization methods are described, as well as the OBU operation. Then, we show a first step in the development of the proof-of-concept, the technologies and challenges related to its implementation. Finally, two user cases are presented, one related to the interoperability between systems and the other targeted to a car sharing system.

II. Motivation

The C2S proposed in this paper is specially developed to ORT infrastructures and it consists of a new OBU that integrates the most used technologies on toll collection: DSRC and GNSS, with a smartphone mobile application, providing new features to the users, such as:

- A mobile application with a user-friendly interface, which provides several types of information (e.g. road prices, best routes, tolls to pay, selection of the payment method / bank account, etc.);
- A new payment method based in NFC, that many believe to be widely used in a near future – user simply touches the OBU with a smartphone and collects all the bills to pay.

Moreover, gathering the characteristic of this system proposal, there is an opportunity to establish a new mechanism of interoperability between the different technologies used on toll collection [7], since the C2S OBU proposal combine the two technologies used on most of the actual systems.

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III. C2S OVERVIEW AND ARCHITECTURE

The idea to create this system arises from the expectable demand for mobile applications and NFC technology to pay bills. This system proposal breaks the current paradigms, introducing the possibility of flexible payment after incurring on tolls.

In most ORT infrastructures this system will follow the process illustrated in Figure 1: the C2S enabled vehicle acts as an OBU that is not recognized by the conventional DSRC tolling system. When it passes on tollbooths, the enforcement system is triggered and the Automatic License Plate Recognition (ALPR) takes a picture; however, the C2S OBU saved the toll and it provides the possibility to pay in a legal time period.

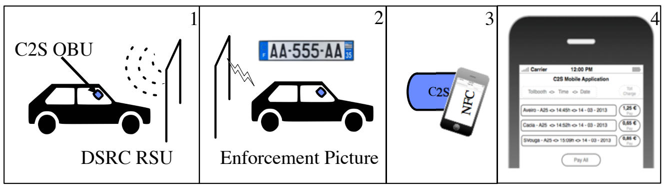

Figure 1 – Utilization steps.

So, basically, there is an OBU, called C2S, that collects the tolls while the user is driving. After the travel, the user can transfer all the toll logs to a smartphone (with NFC) by a simple touch and pay the tolls via a mobile application, in a legal time period (e.g., one week).

Although it seems awkward, there are some niche markets interested in a log and post payment, as discussed bellow in use case scenarios.

A. *OBU Architecture*

The base of C2S is a new OBU composed of several blocks, as illustrated in Figure 2, and implemented on an embedded computer that provides General Purpose Input/Output (GPIO) and USB ports to connect with a GPS receiver, a DSRC Beacon Service Table (BST) detector and the NFC interface. The embedded computer runs several processes to control those peripherals. On the block diagram, in Figure 2, we also included a smartphone as an element of the system because it is where the user interface and a mobile application which communicates with the system OBU via NFC are implemented.

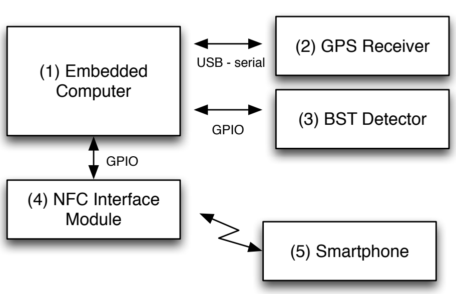

Figure 2 – Overall on-board system block diagram.

The main block is an (1) embedded computer that receives all information from a (2) GPS locator and a (3) BST detector. The GPS locator is responsible for tracking the vehicle and setting time/date when the OBU is turned on. The BST is the first message received from the Road Side Unit (RSU) in a DSRC toll system. Its detector is a small radio device that triggers a signal to the embedded computer when the vehicle passes in a toll. Finally, this OBU can establish communication with a smartphone (with a mobile application) via NFC.

B. *OBU Operation*

The OBU operation is divided into several steps, as illustrated in Figure 3:

- When the system starts, it sets the time and date via GPS and determines if the vehicle is on a DSRC or GNSS/GSM infrastructure;
- In case of a DSRC infrastructure, when a vehicle (with this OBU) passes in a toll, it detects a BST and saves its location via GPS receiver; If the vehicle is in a GNSS/GSM infrastructure, it will track the location and find the position of virtual tolls;
- If the toll is valid to pay, the system saves the information about date and tollbooth location;
- During the road trip, the user has only to touch his smartphone with the OBU and the data containing the tolls to pay is transmitted to the mobile. So the user can check via mobile application how much he has to pay for the tolls;

Finally, the user has to pay the tolls in a legal time period, via a web service.

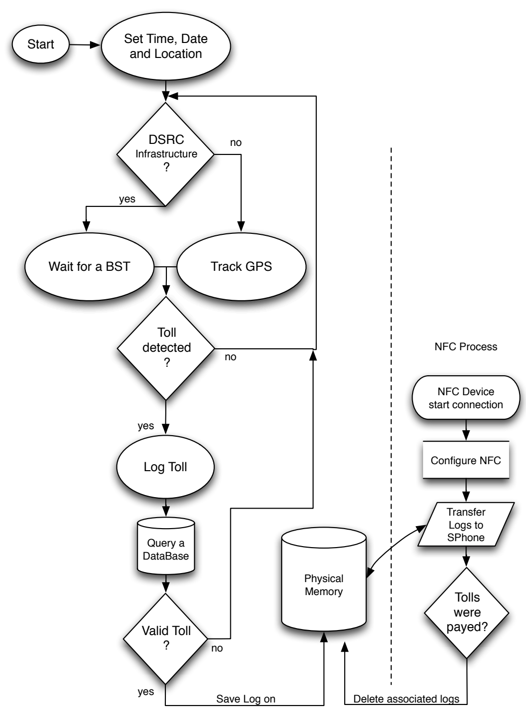

Figure 3 - Operational flow diagram.

The web service component and mobile application are outside of the scope of this paper, but it is worth to mention that the ability to specify the payment method, the bank account and other options can be provided.

IV. PROOF OF CONCEPT IMPLEMENTATION

To build a proof-of-concept prototype, in order to test the functionality of the system, we chose a cheap and widely used computer called Raspberry Pi (RPi) model B as host computer and a GPS receiver [9] attached via USB-Serial was employed, as illustrated in Figure 4.

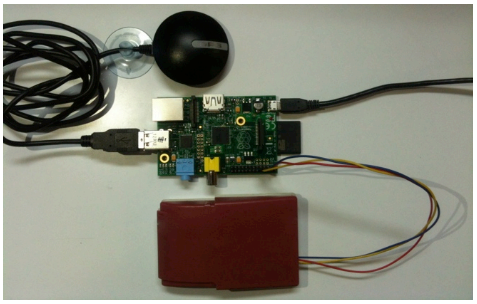

Figure 4 – Prototype - RPi, USB GPS Receiver and BST Detector.

Running on Raspberry Pi is the lightweight and flexible Arch Linux distribution. As already mentioned, there are three peripherals on the system: BST detector, NFC module and GPS receiver. The BST detector simply triggers an interrupt via GPIO pins. One possibility to connect the NFC module is via RPI UART (Universal Asynchronous Receiver/Transmitter). Finally, to communicate with the GPS receiver, it was used the GPS daemon (*gpsd*) service. It is a service that monitors the GPS receiver organizing the sensor data (like location or velocity) to be queried by a client session.

A. GNSS – GPS receiver

The *gpsd* service is widely used because it is easier to parse information compared with NMEA 0183 (National Marine Electronic Application specification) emitted by most GPSes [10]. On the other hand, it recognizes different sensors and it can sniff all the incoming data with zero configurations, it is almost plug and play.

Although the *gpsd* is an open-source project, it has quality and it is an audited code, which already won the Good Code Grant from the Alliance for Code Excellence [11].

Figure 5 illustrates the dataflow diagram. When the sensor receives a signal it fed the packet sniffer, which has the job to tell core library that contains payload to be interpreted. The driver determines the type of packet information. When the packet reaches the end, the data is sent to an exporter to be available to a client. The main exporter uses sockets where an object is generated in JSON and it is provided to all the clients that are watching the device. There is also the option to export data via Shared Memory or via D-Bus [12].

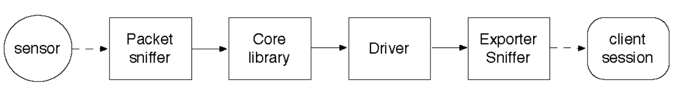

Figure 5- GPS dataflow [12].

The *gpsd* service includes a linkable C service library that encourages developers to use it on their applications. So, the objective is to implement a program, which launches a process that configures and creates a client session.

On GNSS/GSM infrastructure, the client session will track the GPS and compare its location with the fix locations of virtual tollbooth. Here, there is an implementation challenge. To increase the efficiency of the system it is important to define a strategy of how to determine if the vehicle incurred on tolls. One option is to use a data structure that sorts the location of tollbooths by route, i.e., tracking few points it determines in which route the vehicle is and predicts which is the location of the next tollbooth, as illustrated in Figure 6.

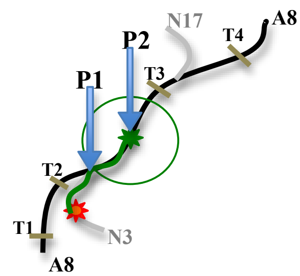

Figure 6 – Route Tollbooth.

The process has a cache memory where the recent positions are saved and compared to each other. For example, sampling two points: P1 and P2, illustrated in Figure 6, it is possible to define a path, to assign it to a route (A8) and then to predict the probable next tollbooth (T3). This approach is in progress and under study.

On DSRC infrastructures, we do not have this problem. Due to BST detector, a flag is raised when the vehicle passes on tollbooth. So, a process logs the position of tollbooth and subsequently compares this with a database of tollbooth locations, to infer the validity of the logging and offer other type of information to the user (price, etc.).

B. General purpose Input/Output pins

Using the GPIO and a simple electronic circuit to control a Radio Frequency module, it is possible to activate an interrupt a line of the host computer (Raspberry Pi).

Finally, the GPIO will be also used to connect to a NFC device via an UART to subsequently communicate with the smartphone mobile application. The goal is to implement a communication based on NFC, because it is a user-friendly technology and, at the same time, secure, as it implies that anyone who wants read, the data of the OBU, has to touch on it so she/he has to be inside of the vehicle.

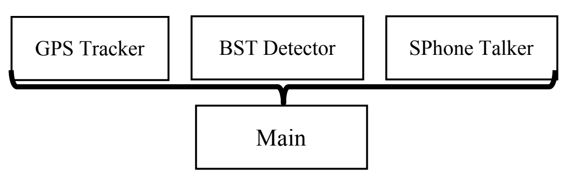

Figure 7 – Primary embedded computer processes.

Briefly, there are several processes: GPS Tracker, BST Detector and Smartphone Talker. These support the main process, illustrated in Figure 7, and together implement the algorithm presented on operational diagram from Figure 3.

V. USE CASE SCENARIO

In some countries, there are user needs that are not satisfied on ORT infrastructures due to the limitations already mentioned. The two issues already listed are the lack of interoperability and a factual case related to car rental or car sharing.

A. Interoperability

One of the most unreasonable restrictions on ETC from the user perspective is the lack of interoperability between distinctive ETC systems of different countries, illustrated in Figure 8. For example, in Europe, there are systems based on same technology (DSRC) and there are countries that use different systems, like Germany that uses GNSS-GSM [13]. In both cases there is no evidence of interoperability between systems. If a driver wants to go from Nice to Aveiro he has to use the manual toll collection systems or travel on national routes, or in worst case, if he has to do it frequently, affix several DSRC electronic tags on his vehicle.

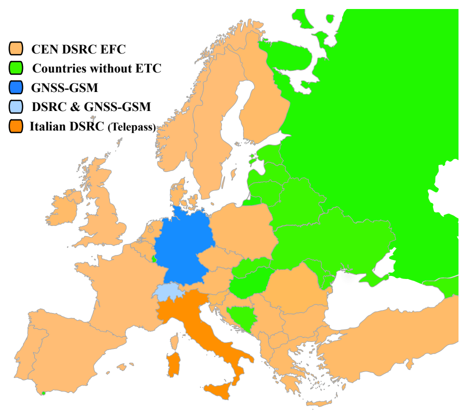

Figure 8 – Distribution of the systems in EU.

From the economical perspective, the road-networks are essential to support the competitiveness, sustainability and success of the markets between states that share long line land borders [7].

So, to address these issues, the European Commission decided to create a European Electronic Toll Service (EETS), launching the Directive 2004/52/EC and related Decision 2009/750/EC [7]. The main objectives are to establish interoperability and to reduce the proliferation of incompatible systems in European Union. The project takes into account technology already implemented and aims to create a road-usage declaration by means of a single OBU.

Following the directive, the C2S proposal constitutes a system technologically compatible with the existing systems. Moreover, the system conceptually ensures interoperability between systems. The user can drive on GNSS-GSM or DSRC infrastructures. The C2S saves the incurred tolls and makes them available for payment in real-time. The user has only to access to the pay web platform (which can be via mobile application), paying in the preferable method, in a legal time. This feature allows users to pay when they have a good and cheap Internet connection (e.g., WiFi) and it represents an advantage to the GNSS-GSM systems where the payment is made via GSM [3]. To implement this feature, it is only needed that each toll company of each country creates a web platform available to the user that receives all the toll payments.

B. Car Rent/Sharing

Another pitfall of the actual systems arises when a costumer rents a car or uses a car sharing service (in a vehicle without an OBU) and passes in an ORT tollbooth. The enforcement system is triggered and a picture is taken and the vehicle is identified via ALPR system. So some time later the rent car company receives the toll receipts to pay the expenses of some costumer. So usually the company sends the receipt to the costumer that probably already left the country, in case of tourism or business travels and then it charges the expenses on the credit card associated with the rent car contract [4]. Otherwise, if the costumer is still around, he can pay the tolls for example in central post office or in a pay shop.

In both cases, the current system causes troubles to costumers, which undeservedly do not understand the information and easily are driving on an ORT. It also causes problems to the hire firms that have to install OBUs on their vehicles and even then do not solve the problem, since the receipts are sent only 48 hours after the incurrence, so the costumer already left the country.

The C2S solves this problem with a simple feature of providing to the rent car company a toll declaration of each costumer. Using a simple and cheap OBU (C2S), it is possible to know if the vehicle incurred tolls just touching a smartphone or a NFC reader to the C2S OBU.

VI. CONCLUSION AND FUTURE WORK

The number of ORT infrastructures is increasing, based on their benefits for the user and the reduction of operational costs for toll companies.

However, these systems have some limitations and do not answer to the requirements of some users, such as rent-a-car costumers, car sharing users and foreign drivers.

The C2S will allow any road user to pay easily the incurred tolls in a friendly user interface.

For now, the system is a work in progress project with the main system blocks, interfaces and communication technologies already operating.

For the future work, we need to develop an application that transfers all the toll data to the toll provider, via mobile application, so it is essential to create an API (Application Programming Interface), in toll providers systems. Finally, to conclude the proof of concept, it is required to test this solution in real scenarios, across several countries in different systems.

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