VIRTUAL TOLLING SYSTEM

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ABSTRACT

Direct payment of motorway toll on expressways and motorways is nowadays a common situation. Toll payment does not serve only as a mean how to pay for utilization of road construction, but it is also a mean how to control and manage mobility on motorways.

This work offers a prototype of Virtual Tolling System (VTS) utilizing satellite positioning system to monitor mobility on motorways and possibility to substitute present manual and electronic solution using Dedicated Short Range Communication (DSRC) technology. VTS is embedded system providing great functionality and may be integrated in future electronic payment systems offering extended transportation services for customers.

1 INTRODUCTION

This project was aimed to design a virtual toll collection prototype which can be considered as a mean of toll payment policy for next generation of charging systems. Virtual toll collection offers possibility to substitute the present solution using DSRC technology where international interoperability is greatly difficult, far away of simplicity, and proposes an extension of Electronic Toll Collection (ETC) services.

With a help of On Board Unit (OBU), a mandatory device installed inside the vehicle and equipped with algorithms for detecting a virtual toll, an area based on the geographical positioning, VTS registers vehicles passages through these designated points which replace toll stations. Also ensuring of faultless system run is implemented by means of security management algorithms that are able to correct system errors caused by an unexpected driver behavior, hardware malfunction or other related failures which can happen in real scenario. The most probable vehicle passage through motorway segment is charged if an error occurred. In most of the cases the security system analyses the real passed trip. It means that neither motorway operator nor driver don’t have any pecuniary loss.

Necessary system interoperability is considered and is connected with integration to the Intelligent Transport System – Integration Bus (ITS–IBus), an open integration bus that is being developed at ISEL[1] in cooperation with BRISA[2].

[1] ISEL – Instituto Superior de Engenharia de Lisboa
[2] BRISA – Auto-estradas de Portugal S.A. (a Portugal main motorway operator).

2 VIRTUAL TOLLING SYSTEM

Virtual Tolling System (VTS) using OBU is autonomous prototype of motorway toll collection system based on principles of Global Navigation Satellite System - Cellular Network (GNSS/CN), see Fig. 1. VTS is designed to manage mobility on motorways. Motorway charging has evolved to kilometre based charging where covered distance is regarded as scale for exact toll amount calculation. Therefore VTS mainly serves for data acquisition which would serve as parameters important for assigning of toll amount.

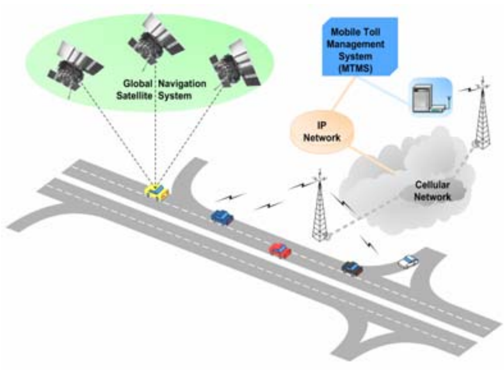

Fig. 1: *VTS architecture overview*

It is necessary to obtain information about the entrance point and the exit point. After sending of these information (as well as time and date of transaction) over cellular network, the toll assignation process can proceed in *managing center*.

VTS does not need to serve only as an ETC system but through OBU provides unique opportunity how to track significant parameters of vehicle's behaviour. Accordingly the OBU can integrate emergency management components to provide for instance quick incident notification (e.g. accident, traffic congestion, etc).

2.1 ON BOARD UNIT

The OBU of VTS include an equipment intended for a satellite signal acquisition (GPS receiver) and perform its high processing in OBU's computing unit controlled by programme code. Communication does not involve only receiving the GPS broadcasted signals but also communication between vehicle and *managing center* using a cellular network, see Fig. 2.

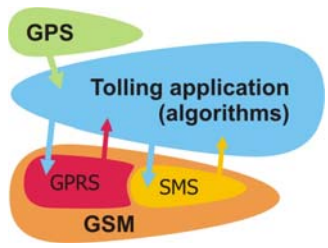

Fig. 2: *OBU architecture*

All the technology enables OBU to determine vehicles position and by comparative analysis of this information to control the flow of the operations and according to varying conditions to decide, when is necessary to communicate with managing center.

Fig. 3: *OBU (Nokia12/ M12)*

Two types of OBU have been established. The solution based on PC/104 and Motorola G18 module and more sophisticated solution (see Fig. 3) with Nokia N12 and Motorola M12 modules.

2.2 CELLULAR ARCHITECTURE

Cells, the areas based on the geographic coordinates, are representing virtual toll stations, see Fig. 4. The word "virtual" actually means that the toll station does not exist and therefore there is no need to install any kind of equipment.

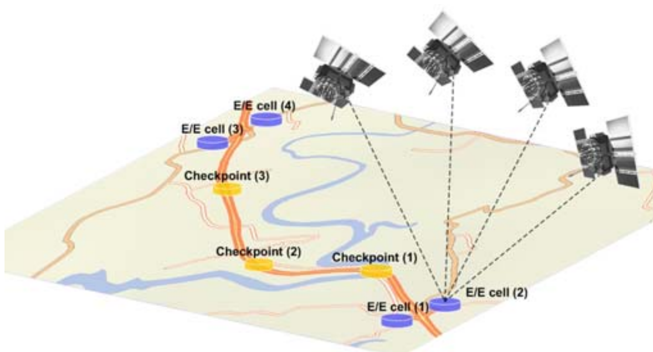

Fig. 4: *Virtual Tolling System Architecture*

It is necessary to specify precise location (dedicated by coordinates) representing toll stations, a center of an area within 90 m radius, which is sufficient for errorless GPS detection.

Two types of cell are distinguished:

- *Entrance* / *Exit* (*E/E*) cell – Represents entrance or exit point and serves as an evidence of entering or exiting the motorway. In VTS *E/E* cells substitute charging points (toll stations) on the beginnings of charged roads.
- *Checkpoint* cell – Represents a cell placed anywhere on the motorway between two *E/E* cells. *Checkpoints* continuously monitor vehicles movement and serve for security purposes.

The OBU contains a database with designated locations of the cells and registers the passage when vehicle passing one of these charging points.

2.3 CELL DATABASE

Each cell is defined by several parameters that uniquely determine its identification in whole list of all cells, see Fig. 5. With regard of their often performance in OBU the structure was designed to enable quick and easy browsing for particular records.

Parameters not only specify a cell location and unique identification but also country where is located and operator who belongs to and also references to next or previous cells and their azimuthal directions. Database references are the most important features and play crucial function in searching in the database. The OBU is possible to determine following or previous cells due to the azimuth calculation.

	lat	lon	curCellID	curCellType	countryCode	operatorCode	nextCellID1	azimuth1	nextCellID2	azimuth2	nextCellID3	azimuth3	nextCellID4	azimuth4	info
1	38.719722	-8.959552	100	1	351	1	101	299.70							VascoENT
2	38.726100	-8.985270	101	2	351	1	102	300.00	100	120.00					VascoCH1
3	38.741573	-9.015283	102	2	351	1	103	317.55	101	137.55					VascoCH2
4	38.761940	-9.042645	103	2	351	1	104	316.08	102	136.08					VascoCH3
5	38.778323	-9.064671	104	2	351	1	105	311.93	103	131.93					VascoCH4
6	38.786240	-9.091901	105	1	351	1	104	130.00							VascoEXT

Fig. 5: *Cell Database*

As a result, the database is stored in exactly defined data format inside the OBU where one row is comprised in sum of 34 to 49 bytes. In this way the original text file size is lessened about 26% and 52% (in dependency on number of the references) and in addition unreadable for unauthorized persons. Therefore maximum number of providers is 127 and each can have registered maximum of 32767 cells.

2.4 VTS OPERATION

After initialization, OBU starts cell detection algorithm in a loop and waits for cell appearance. The OBU calculates the direction (azimuth) of moving vehicle when a cell is detected. This value is being calculated every time and is necessary as a reference in the case of unexpected failure. Then the OBU reads several flags recording the state of OBU application (thus the progress of the trip) and finds out the sate of affairs.

The crucial condition is an *Entrance* to the motorway and *Entrance Acknowledgement*. Due to these two conditions OBU finds out if vehicle follows “regular passage” or not. In the case of “regular passage”, see Fig. 6, the first cell that OBU should detect will be *E/E* cell representing the entrance point to the motorway.

After successful detection of the *Entrance*, OBU waits for a first appearance of the following cell (*Checkpoint*) which is related to *Entrance* through the reference. Both are compared by means of their references. The *Entrance* becomes acknowledged if comparing was successful. From this moment it is for sure the vehicle is on the motorway. When OBU detects another *E/E* cell and vehicle has already passed through one *E/E* cell (a regular entrance) this will be taken as an abandonment (exiting) of the motorway.

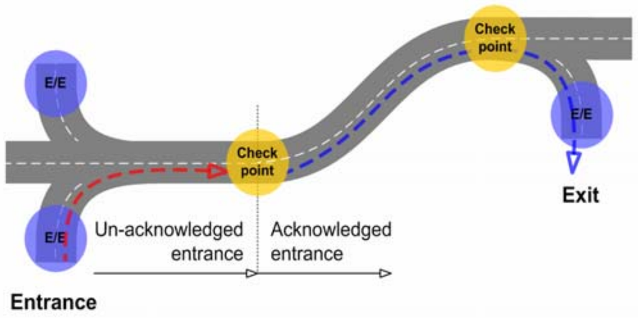

Fig. 6: *Regular motorway passage*

In the second case of "irregular passage" method called *Cell prediction* is used. Necessary for its understanding is to know that the method tries to find an *Entrance* by browsing the cell database using the azimuthal reference. The *Entrance* prediction is used in cases when there is no regular entrance or when some failure disables *Entrance Acknowledgement*.

During a vehicle drive, the OBU creates a temporary cell database serves as a local map of the cells selected from the whole database file for quicker searching. This is more appropriate solution instead of the slow repetitive access into the database file. Both, entrance and exit are saved in OBU and can be transmitted to the *managing center*.

2.5 SECURITY MANAGEMENT

Unexpected traffic situations may occur due to the GPS error's dependency on the weather conditions, on the urban environment or by an unusual driver decisions. These occasions causes improper functioning of the VTS and thereby also billing malfunction. Therefore was essential to determine main error situations that involve all possible error appearances and finds out universal solution for their system correction.

Security algorithms are based on comparison of a nearest predicted *Entrances*. In the case of error state, on each *Checkpoint* starts prediction processes until the nearest *Entrance* is acknowledged. Predicted *Entrances* don't have to be the same, but if at least two *Entrances* are identical, the *Acknowledged* entrance is set after comparison. Now, the vehicle is registered on a motorway and the rest proceeds as in chapter 2.4. This simple mechanism is able to involve the major failures such as:

- Error on *Entrance*
- Error on first *Checkpoint*

Due to an infelicitous cell locality selection another failure may occur. A quite common example is when a not charged road is situated near a motorway.

- Accidental *Checkpoint* crossing

The vehicle's OBU detects a *Checkpoint* cell on a not charged road. A condition, that at least *two passed cells* on the same motorway are necessary for a vehicle confirmation on a motorway ensures the proper system run. It's necessary to carefully consider cell position.

2.6 COLLISION AVOIDANCE

The OBU universality offers integration of additional services. For a fluent and save traffic on motorways is useful to insert collision situations monitoring and prediction into the VTS. A common collision situation is identified as traffic congestion, vehicle breakdown or low velocity by the simple mechanism using velocity slope calculations. Obtained warnings are transmitted to the *managing center* via cellular network.

2.7 COMMUNICATION

The GSM network offers the best signal coverage of present wireless networks, service reliability and provides multifunctional communication services. The SMS or GPRS services are used for communication between a vehicle and motorway operator *managing centre* and back. The OBU is able to update *Cell Database* via GPRS on request from *managing centre*.

A common communication is realized through the use of predefined message format. Two message types are distinguished:

- *Acknowledgement* message
- *Toll Pay* message (see Fig. 7)

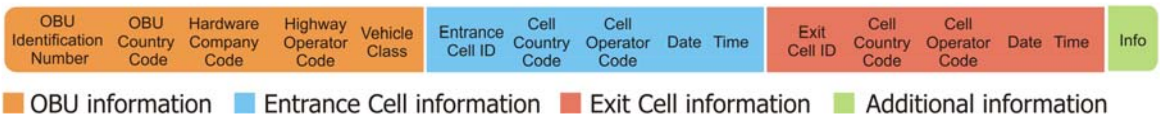

Fig. 7: *Toll Pay message format*

3 CONCLUSION

The Vasco de Gama bridge as a real scenario of toll payment has been chosen for purpose of algorithms testing, see Fig. 8. The OBU approved an autonomous and faultless ability of motorway toll collection hence substitution of present EFC systems. The possibility of simply future enhancement is one of the main system advantages.

An easy interoperability implementation and functionality make from the Virtual Tolling System suitable solution for next generation of Electronic Fee Collection systems.

Fig. 8: *Vasco de Gama scenario*

REFERENCES

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[2] Vojáček, M.: Virtual Motorway Toll Collection Prototype Using On Board Unit, M.Sc. thesis, Brno University of Technology, Department of Telecommunications, July 2004