



## THE FUNCTIONAL STRUCTURE OF THE NATIONAL AUTOMATIC TOLL COLLECTION SYSTEM

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### Abstract

The paper refers to European Electronic Tolling Service (EETS) implementation in Poland. According to Directive 2004/52/EC, EETS should use one or more of the following technologies: satellite positioning, mobile communications using the GSM-GPRS standard and 5,8 GHz microwave technology. The European Commission adopted a decision (6 October 2009) setting out the essential technical specifications and requirements needed to launch a EETS which will enable road users to easily pay tolls throughout the whole EU thanks to one subscription contract with one service provider and one single OBU. EETS will be available within three years for all road vehicles above 3,5 tones or allowed to carry more than nine passengers, including the driver. It will be available for all other vehicles within five years. Motor Transport Institute has developed the structure of the National Automatic Toll Collection System (NATCS) for motorways and expressways for Poland. NATCS consists of National Automatic Toll Collection Centre, OBU and control subsystem. NATCS system is based on a combination of mobile communications technology (GSM) and the satellite-based global positioning system (GPS). An innovative element of NATCS - OBU will have many advantages as follows: fast installation by user in wind shield, reduction to minimum costs and components, GPS Receiver with high quality, GSM module, DSRC module in order to spread services and interoperability with other systems in EU. The control subsystem distinguishes between automatic enforcement through control gates, enforcement by mobile teams, and patrol teams.

*Keywords: EETS, GPS/GSM technology, DSRC technology, OBU.*

### 1 Introduction

Electronic Toll Collection (ETC) is a fairly mature technology that allows for electronic payment for motorways and expressways. An ETC system is able to determine if a car is registered in a toll payment operator, alerts enforcers of toll payment violations, and debits the participating account. ETC is fast becoming a globally accepted method of toll collection, a trend greatly aided by the growth of interoperable ETC technologies.

There are two different types of European Electronic Tolling Service (EETS): Dedicated Short Range Communication (DSRC) and GPS/GSM based systems.

The first system (DSRC) is typically used as the primary method of charging where a charge is to be applied at one of a discrete number of specific points, such as a toll plaza (an area where tollbooths are located) or a location on the open highway. DSRC can be either closed (cordoned) or open. The closed system requires entrances and exits based on toll booth (a booth at a tollgate where the toll collector collects tolls). In an open toll system, toll stations are located along the facility. It is the collection of tolls on toll roads in three or more adjacent lanes without the use of lane dividing barriers or toll-booths. The major advantage to open system is that cars need not stop nor even slow down for payment.

The elements of toll system like transponders (tags) mounted on the vehicle's windshield, have got the same dimensions (box of cigarettes), but for every kind of system the vehicle should be equipped with different transponder (Fig. 1), for example Go-Box in Austria, Premid in Czech Republic, Passango in France.

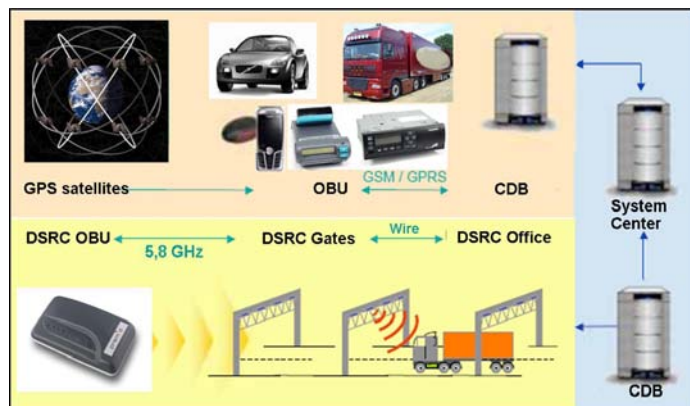


Figure 1 Scheme of dsrc and gps/gsm based systems (Based on McKindlay, A., 2006.)

The second system is based on an innovative combination of mobile telecommunications technology (GSM) and the satellite-based Global Positioning System (GPS). The main element of the automatic log-on system is the On-Board Unit (OBU). With the aid of GPS satellite signals and other positioning sensors, the OBU automatically determines how many kilometers have already been driven on the toll route, calculates the toll based on the vehicle and toll rate information that has been entered, and transmits this information to the computer centre for further processing. Software will be supported with electronic road maps and data of users registered as well as data charges of highways and expressways. The electronic toll collection systems in the European Union member states are not interoperable due to differences in charging concepts, technology standards, classification and tariff structure, legal and institutional backgrounds (Fig. 2).



Figure 2 Existing EETS model in European Union

European Commission has taken bold steps to address that issue. The first one was Directive 2004/52/EC of the European Parliament and of the Council of 29 April 2004 on the interoperability of electronic road toll systems in the Community [3].

According to Directive all new electronic toll collection systems brought into service on or after 1 January 2007 shall, for carrying out electronic toll transactions, use one or more of the following technologies: satellite positioning, mobile communications using the GSM-GPRS standard (reference GSM TS 03.60/23.060) and 5,8 GHz microwave technology. The requirements of that directive will be implemented in Poland based on the Act from 7 of November 2008 and some other acts [7]. It stressed that toll collecting charge institutions should be able to carry out electronic toll transactions from 1 of July 2011.

The second was decision to launch Europe's own Galileo system, that is predicted to improve upon both the accuracy and reliability of GPS. On June 26, 2004, the US and EU signed an agreement to coordinate Galileo and GPS.

The third was Commission Decision of 6 October 2009 on the definition of the European Electronic Toll Service and its technical elements [1].

## 2 Technical and economical aspects of EETS

According to data presented by EFKON AG [8] the implementation costs of Electronic Toll Collection System using GPS/GSM technology are a little more (about 20 %) than Dedicated Short range System (DSRC) in the beginning implementation including roadways below 1000km and assumption of 300 000 on-board units (OBU's).

The costs of mentioned systems are equal in roadways total number of 1000 km. Furthermore, above 1000 km, the costs of GPS/GSM based system are getting definitely decreased (to 60 % with total number of roadways – 3000km), but the costs of DSRC system are decreased only a few percent (Fig. 3).

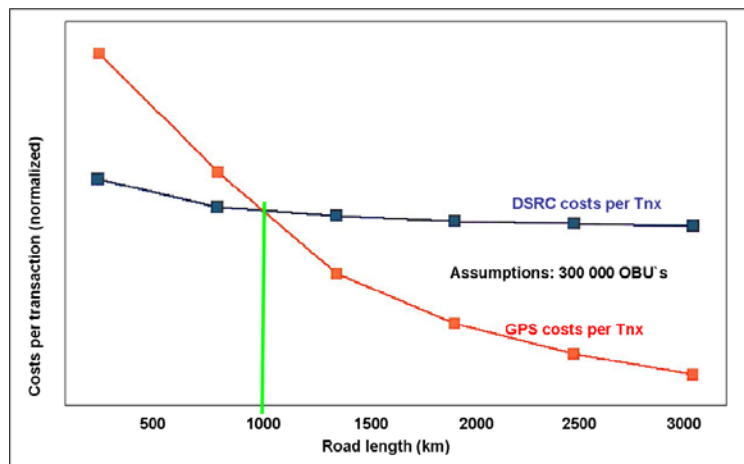


Figure 3 EETS implementation costs comparison between DSRC and GPS/GSM systems

For road networks >1000km European Electronic Toll Service using GPS/GSM technology is higher cost-efficient. Charging secondary roads/extending network with using GPS/GSM technology is the choice.

The profit of Electronic Toll Collection System (DSRC) in Czech Republic implementation was 213 million Euros in 2007 and 236 millions Euros in 2008 (Černý, V., 2009). There were 357 000 registered OBU's in 2008, and 380 000 OBU's in the beginning of 2009.

The daily profit of using DSRC system in Czech Republic is 740 000 Euros. Based on analyzes it is known that profit of operating system will be 2,5 billion Euros by 10 years [2].

The implementation cost of Toll Collect System in Germany was about 1 billion Euros. Yearly profit from system is 3,5 billion Euros [9].

**Table 1** Comparative study of EETS [5]

Characterization	Austria [6]	Czech [2]	Germany <sup>2</sup>
Introduction date	01.01.2004	01.01.2007	01.01.2005
Admissible weight	> 3,5 tony	> 3,5 tony	> 12 ton
System cost	1010 M€ <sup>3</sup>	780 M€ <sup>4</sup>	1240 M€ <sup>5</sup>
Technology	DSRC	DSRC	GPS/GSM
Tariff/km	0,155 € 0,217 € 0,325 €	0,068 € 0,11 € 0,15 € 0,21 €	0,09 € 0,10 € 0,11 € 0,12 € 0,13 € 0,14 €
Average charge	0,26 €	0,124 €	0,115 €
Budget revenues (2008)	825 M€ 12 %	236 M€ 5 %	3,5 B€ 22 %

- 1 According to German Ministry of Transport, Construction and Urban Development: [www.bmvbs.de](http://www.bmvbs.de)
- 2 The company ASFINAG, responsible for the introduction of the EFC system, decided finally for the Italian motorway operator Autostrade S.p.a. as the best bidder in the evaluation process. Autostrade, respectively its Austrian subsidiary EUROPPASS signed a contract. The contract has an equivalent value of 750 million Euro. The operator users for Toll collection a microwave based DSRC technology, 5,8 GHz compatible to the CEN standard with road-side radio-antennas on each motorway section between junctions. The implementation of the system took 18 months as it was requested in the tender. Source: PIARC Seminar on Road Pricing with emphasis on Financing, Regulation and Equity. Cancun, Mexico, 2005, April 11-13 1/8. Additional Construction cost of the nationwide truck toll system for Austria is about \$340m (E260m) using 2005-03 exchange rate \$1.3=E1. Source: Toll Road News.
- 3 The Transportation Ministry announced in early October (2005) that the system has cost 780 Million Euros for the Czech Republic, and was promised to give return on investment by 2010. The consortium of Ascom Fela, Damovo and ABD group presented the lowest bid. The consortium requested 15 billion Kč (530 Million Euros) with which to build and run the electronic toll system for 10 years. Meanwhile, Autostrade has offered its system for 17.5 billion Kč (620 Million Euros), Kapsch/PVT has asked for 22 billion Kč (780 Million Euros); and a consortium of A-WAY, AZD Praha, Efkon and EGIS Projects proposed 33.7 billion Kč (1200 Million Euros) to build and run the system. The system has cost 780 Million Euros for the Czech Republic, and was promised to give return on investment by 2010.
- 4 Based on: [www.bmvbs.de](http://www.bmvbs.de)

One of reasons to introduce Toll Collect in Germany was problem to check exactly routine of trucks, especially invaders and mistakes in fee calculations. The monitoring data: who, when and why goes this way no other in DSRC system depends on many persons and more time, what increases cost of operating system.

Furthermore in free space microwaves (5,8 GHz) travel in straight lines as do optical waves. Near the Earth, however, the atmosphere has an index of refraction which normally decreases with distance above the Earth and causes the wave to travel in a circular path which bends slightly toward the Earth. Microwaves are reflected and refracted by objects just as are optical waves.

Reflection effects can severely degrade the performance of electronic toll collection systems in which communication must take place between a fixed road side system and an on-board unit (OBU) in a moving vehicle [6]. This degradation is caused by destructive and constructive interference between the direct-path signal and reflected signals. Such interference will also occur in systems using circularly polarized waves. Depolarization will also have a negative influence on the communication.

Taking into consideration problems of microwave propagation, especially in urban and mountain areas, Czech Republic Government signed new contract with Kapsch in 2008 to implement hybrid system, which includes DSRC technology in actual roadways (972 km) and new GPS/GSM technology on new motorways and expressways.

### 3 NATCS for Poland

Examples of Intelligent Transportation Systems applications may include: commercial vehicle operations, crash prevention and safety, electronic payment and pricing, emergency management, freeway management, incident management, information management, intermodal freight, road weather management, roadway operations and maintenance, transit management, traveller information.

The Motor Transport Institute has created the structure of The National Automatic Toll Collection System for Poland (NATCS). System will consist of The National Automatic Toll Collection Centre (NATCC), control gates, on-board units (OBU) and control subsystem (Fig. 4).

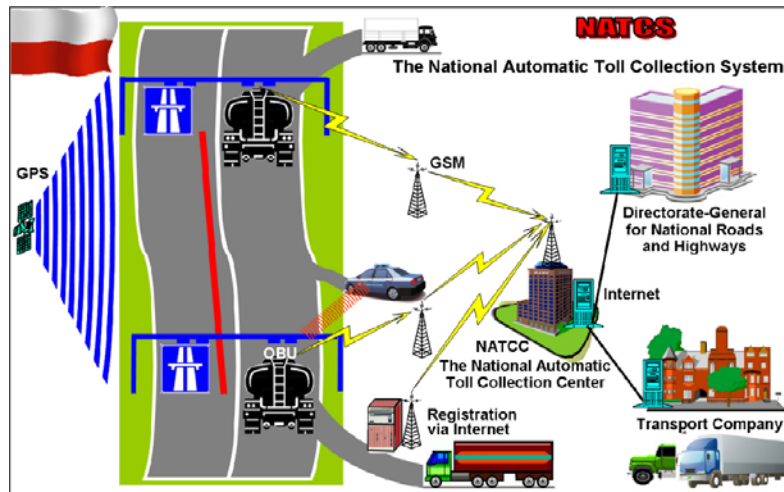


Figure 4 The structure of the NATCS

The National Automatic Toll Collection Center (NATCC) based on telematic system approved all functions performed for the National Automatic Toll Collection System (NATCS). The NATCC elements are as follows:

- 1 Redundancy servers.
- 2 Applications and system software.
- 3 Data bases.
- 4 Interfaces:
  - between NATCC and OBU,
  - between NATCC and control gates,
  - between NATCC and external systems (bank systems, Internet charge operators, Central Evidence Systems of Drivers and Vehicles).
- 5 User interface – www Internet service, Call Center, sms gate, automatic telephone service.
- 6 Data transmission nets (WAN, LAN).

Data bases can be divided into following groups:

- Data of users, vehicles and charges.
- Physical Network Inventory.
- Dynamic Network Inventory.

Call Center should be used for the users' phone contact. Call Center workers should use special application – www Intranet service in order to verify ID of the person calling and for instance answer the questions and address claims.

The prototype of OBU will be manufactured by FELA. It is a leading company on the Switzerland market that has produced telematics systems. Its experience is based on long-term cooperation with scientific and research institutes as well as on continuous analysis of new technologies that allow creating new telematics solutions.

OBU will be installed in vehicles windshields and realized the following functions:

- Vehicles data storage.
- Digital map nodes and points storage.
- Toll charges calculation based on introduced data (admissible mass, No of axles, emission class, distance, tariff model).
- Analyze data coming from module and sensors (GPS, GSM, DSRC).
- Optical and sound signalization of OBU working parameters (for instance distance, fees).
- Safety data transmission to system and communication with control gates (stationary and mobile).
- Remote data actualization and parameters exchange.
- Data security based on cryptographic module.
- Additional DSRC module to spread services and interoperability.

The system is based on an innovative combination of mobile telecommunications technology (GSM) and GPS, the satellite-based Global Positioning System. The main element of the automatic log-on system is the On-Board Unit (OBU). With the aid of GPS satellite signals and other positioning sensors, the OBU automatically determines how many kilometers have already been driven on the toll route, calculates the toll based on the vehicle and toll rate information that has been entered, and transmits this information to the NATCS computer centre for further processing.

Software will be supported with electronic road maps and data of users registered as well as data charges of highways and expressways.

Charge counting will start after highway entrance gate and finished after highway exit gate. Data on vehicle position will be additionally approved by GPS system and delivered to NATCC by GSM net. The toll amount is based on the truck's emission category and number of axles, as well as on the length of the toll route.

The control system distinguishes between automatic enforcement through control gates, enforcement by mobile teams and patrol teams. This combination guarantees comprehensive, continuous enforcement of the requirement to pay toll and allows the control system to be constantly adjusted to meet prevailing circumstances.

Automatic control subsystem consists of permanently installed enforcement control gates are used to ensure toll requirements are met without interrupting traffic flow. The automatic control gates come complete with (Fig. 5):

- Laser scanner for vehicle detection,
- Laser scanner for No of vehicle axles,
- DSRC Module,
- Camera for registration of the number plate.

Laser scanners on the control gates scan the silhouettes of passing trucks to determine whether they are required to pay toll. A camera takes several digital photos of the truck's number plate. At the same time, DSRC communication is used to determine whether the vehicle is equipped with an On-Board unit. If so, the On-Board Unit transmits the current toll collection data to the control gate, where it is compared with the control data that has been recorded. If the vehicle does not have an On-Board Unit, its number plate is compared against a list of all Internet log-on data. This way, it is determined whether the driver has paid the correct toll based on the number of axles on the truck, its pollution class and the route under review. If the automatic review determines the toll has not been properly paid, the data is transmitted to enforcement headquarters for review. If the results of the automatic review are confirmed, the data is stored and provided to RTI to punish the offense. Once it has clearly been determined that the toll was paid, the data is deleted immediately.

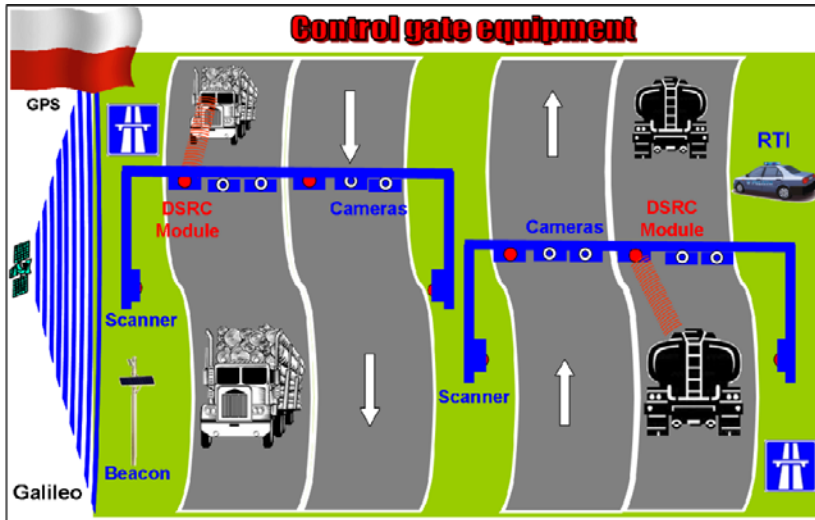


Figure 5 Control gate with other electronic equipment

## 4 Conclusion

For many years, microwave-based digital short range communication (DSRC) systems have been preferred, due to their simplicity of operation, potential for supporting additional services for vehicle users and, most importantly, because they are easy for users to understand. These systems need road-side equipment, typically mounted on a gantry, with electronic tags in the vehicles which may be read-only, read-write or smartcard-based. The key limiting factor seems to be the processing speed of the smartcard – each charging point has two gantries – one to start communications with the vehicle and a second (further down the road) to complete the transaction and perform enforcement measures, if necessary.

A new class of ETC systems is based on a combination of mobile communications technology (GSM) and the satellite-based global positioning system (GPS). An innovative element of the automatic log-on system is the On-Board Unit (OBU), which automatically calculates the amount of charge due and takes into account the emissions class (ecological aspect) and the number of vehicle axles in calculating this charge. The first GPS based system advantage is an absence of the need for new road infrastructure (gantries), while the operators can keep using the existing infrastructure. System works without toll booths, extra lanes, speed restrictions or complex structures along toll roads. The second one is much greater flexibility in defining or changing payment by simply redefining the “virtual” toll areas. It means the ability to adapt easily and quickly to changes in charge parameters (road classes, vehicle types, emission levels, times slots etc). The third is the systems ability to support other value-added services on the same technology platform. These services might include fleet and vehicle engine management systems, emergency response services, pay-as-you-drive insurance services and navigation capabilities.

With regard to future expansion and development, the satellite-based toll collection system will be a better solution, especially with regard to flexibility when it comes to extending toll collection to every road category, every category of vehicle and, what’s more, in terms of cost efficiency in implementation and operation.

## Acknowledgments

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