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Use of Microcomputer Technology in electronic toll systems

Introduction

Mobility is one of the essential elements of modern human society and the transport performance has been continuously growing in the last time. Consequently, the requirements for the infrastructure, the quality and throughput of traffic roads as well as for the information systems are increasing respectively. Apart from the positive impact on trade and population mobility, there are also some negatives, whether pollution of the environment, traffic congestions or traffic accidents.

The society tries to reflect this development on the market, legislative and scientific research basis. The producers place on the market new, more efficient and powerful vehicles, most countries make significant investments to the road infrastructure, new traffic information systems are being built. At the same time there is also increased regulation of traffic laws by state or supranational bodies.

The present study describes the basic technological **tolling solutions**, focusing on the description of their operation. The tolling systems are different to the way vehicles (exactly On Board Units in vehicles) interact with the surroundings. Further necessary part of tolling systems is an interface for clients to contact the operator, whether it is a contact centre, user terminal, payment terminal, OBU distribution point, website etc. Electronic payments, data communication, processing and storing of dates, as well as other supportive technologies are also known under name **electronic toll collection technology**.

1. Microwave (infrared) technology DSRC

The system works on the basis of DSRC[1] data connection between the OBUs[2] in vehicles and facilities at **toll gates** built along the road. Two types of gates are used, i.e. **fee collecting gates**, that detect OBUs in vehicles and by

[1] **DSRC** (Dedicated Short Range Communication) – wireless communication (infrared or radio waves) on short distances between a vehicle and the infrastructure.
[2] **OBU** (On Board Unit) – a technical device (small box) in a car for wireless communication with the toll infrastructure along the road.

communicating with them they prescribe the toll, and **surveillance gates**, that check the accuracy of payments. In open charging system, which is used for example in the Czech Republic or in Austria, there is one toll gate built in each highway section. The number of surveillance gates is lower, as they are not involved in determining the toll.

Charging takes place in the following way: The transmitter on a fee collecting gate activates the OBU in a vehicle, which transmits back the identification of the vehicle (registration number, number of axles). The communication repeats in the following toll point, and the fee is prescribed based on the distance which is travelled. There are two ways of charging, i.e. post-payment and prepayment. The data communication in the pre-payment system includes financial data, too, enabling fluent deduction of finances from the user account. The post-payment system collects data about the road of the vehicle using the toll gates and sends them to the centre, where the toll is calculated and the bill is subsequently sent at regular intervals.

The monitoring system consists of gates equipped with DSRC communication unit and other devices categorizing the vehicles (a camera, a unit to recognize the number of axes of the vehicle etc.). While driving through, the vehicle data which is read from the OBU, are compared with the data detected by the sensors. If a discrepancy between these dates occurs or if the communication fails at all, the vehicle is identified as a potential defaulter and it is passed on the control and enforcement system.

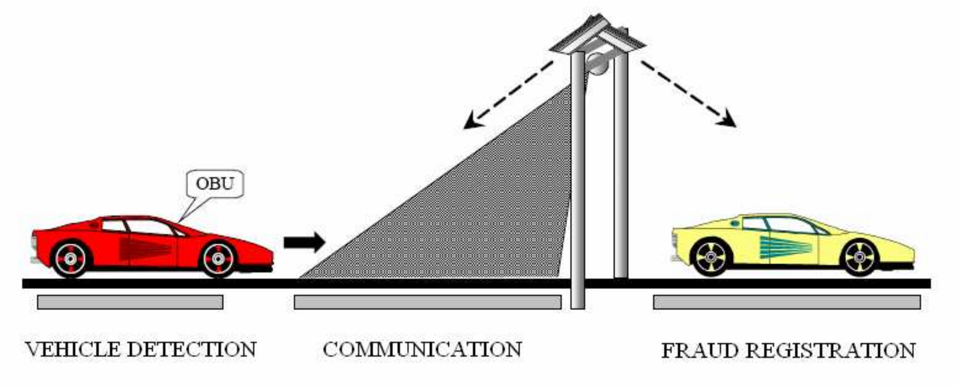

Fig. 1. DSRC operating principle [Janota, Spalek 2006]

The DSRC tolling system requires the construction of toll gates, according to its layout, in the road sections between intersections or at the exits/entrances to the toll road. It can also be used for charging of areas. The OBU is simple, inexpensive and easy to install on the front windscreen of the vehicle. For this reason, the DSRC charging systems are unitary, i.e. the OBU is a mandatory equipment of all vehicles. The DSRC system can be operated parallel to manual charging too. This technology is especially suited to charging exactly specified and limited road network (highways), or as a convenient alternative of **manual payment**, respectively [Přibyl 2007: 197–200; Přibyl, Svítek 2001: 324–327]. DSRC operating principle is shown in Figure № 1.

2. GNSS/GSM satellite technology

GNSS/GSM technology (also called GNSS/CN, GPS/GPRS, GPS/GSM)[3], is based on **satellite positioning of vehicles** and **long-range communication** in GSM network. The system uses a different way to locate the vehicles, but it is fundamentally not much different from the DSRC system. While the DSRC system uses physical toll gates, in the case of technology GNSS/GSM it is about **virtual toll gates**, whose position is stored in a digital database in the center or in the OBU memory. The satellite positioning system GPS is currently used, the European Galileo system is not available for these purposes yet. The charging is proceeded analogically to DSRC. When the positioning system recognizes the vehicle passing through the section, marked in the database as a tax point, the vehicle is charged. Also in this case the pre-payment and post-payment methods are possible, i.e. either continuous deduct of finances from a prepaid card or record the vehicle’s movement on the toll network and subsequent billing.

The OBU contains identification data of the vehicle, further it records passages through the toll points and the payments made. This information is transmitted to the center via a cellular network, using the GSM and GPRS communication protocols. Data transfers occur in the opposite direction, from the center to the OBU too, weather in the case of updating the virtual toll points’ database or for adjusting of rates.

A part of satellite toll is also a static monitoring system, which operates similarly to the DSRC system. It is implemented using surveillance toll gates containing both DSRC module and detection equipment. Likewise in this case it is necessary to choose an appropriate density of control components as a too loose network may degrade the entire system.

This tolling system does not require the construction of extensive infrastructure along the roads, as shown by its principle shown in Figure № 2. An extension of the toll network can be made easily by modifying the software only. The technology is suitable for charging of a large road network and it is used for example in Slovakia and Germany.

[3] **GNSS** (Global Navigation Satellite System) – a technology determinating the user's location, which is equipped with an appropriate signal receiver. The U.S., originally military positioning system GPS (Global Positioning System) is used en masse, in Europe there is currently being introduced a new positioning system GALILEO.

However, a more complicated and more expensive OBU is required. Therefore some states are using a dual system allowing users without OBU to make electronic payments too. The vehicle tracking is then performed by the surveillance system only [Přibyl, Svítek 2001: 328–329; Přibyl 2007: 197–200; Schindler 2007].

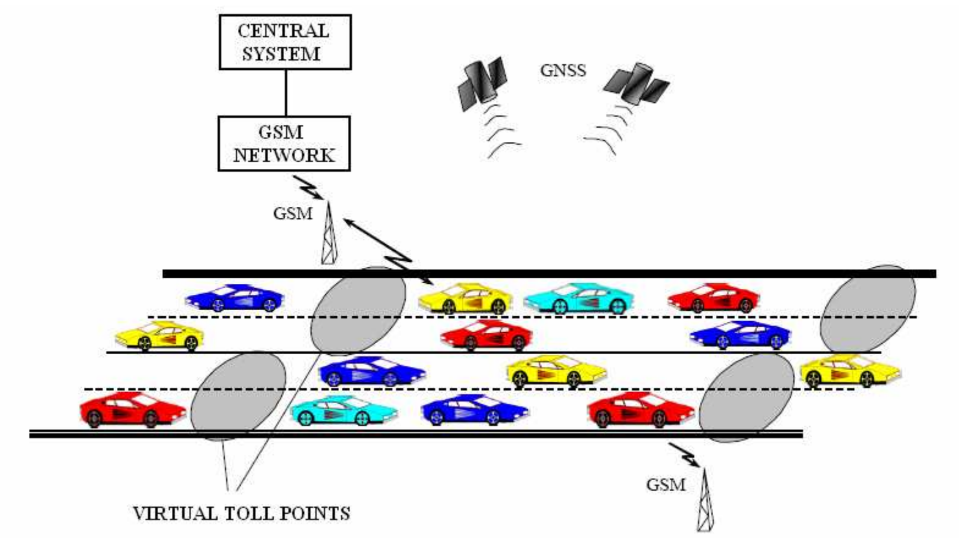

Fig 2. GNSS/GSM operating principle [Janota, Spalek 2006]

3. A hybrid DSRC-GNSS/GSM system

This system with the trade name Kapsch Area was demonstrated as a pilot program in the Czech Republic by Kapsch, being tested on 10,000 users there. It is a **combination of electronic toll systems**, i.e. charging with DSRC technology on existing infrastructure (mainly highways) and GNSS/GSM satellite technology on lower class roads, where the DSRC infrastructure was not built.

The system is designed as a low-cost extension of the existing DSRC system. The advantage is rather easy extensibility of the toll network, if the DSRC technology was chosen at the beginning and the possibility to install toll gates at that places where the GPS signal is not sufficient. There is no need of mass RSE[4] construction, also the OBU is cost saving, which is designed as a very simple and inexpensive, so-called „light", which means easily mountable on the windshield. OBU is interoperable with both technologies; the **mode switch** is done automatically, without any user intervention [Gschnitzer 2007: 12–14].

[4] **RSE** (Road Side Equipment) – infrastructure along a road, a toll gate in general. It is a construction on which communication and detection modules or cameras are mounted. Charging and surveillance gates are distinguished.

Hybrid technology is a potential alternative for states that want to significantly expand their toll network while maintaining the existing DSRC infrastructure, to which considerable resources were invested. It begs the question why the system was not designed from the beginning as a satellite, which would save significant costs associated with previous construction of DSRC toll gates. Advantages of the hybrid system, such as a greater range of telematic services offered, saved data communication charges on the DSRC infrastructure (but not talking about large volume of data communication due to the proxy-client design of the OBU), or sharing of enforcement and centre systems, are quite marginal in this comparison.

4. Possibilities of using the electronic toll collection systems in other telematic applications

One of the key benefits of electronic toll collection represents an opportunity to use them in **superstructural telematic applications**. For this purpose, the data from OBUs, from toll gates, from the surveillance system, as well as from the central database may serve. For example, the electronic toll system in the Czech Republic offers important statistical and operational data to government, usable in transport planning and traffic management. Possibilities of using are far broader, provided telematic services are categorized into the following areas of use [Svítek 2006: 13–14]:

– **services using data from the server component of electronic toll systems**, that use connection of central database with public administration systems, allowing acquisition of various statistics, transport modeling, documents check based on the link to vehicle register etc.;
– **services of OBUs in the DSRC system**, locating vehicles in individual route points; technology can be used to track vehicles carrying dangerous cargo, to measure the travel time between two gates, to detect congestions etc.;
– **services of OBUs in the GNSS/GSM system**, locating vehicles continuously along the route; technology can be used to send data of the current location of vehicles to the logistics center, to provide navigation services, taking account of the current traffic situation, to instant check of the speed of vehicles, to remote vehicle diagnosing, to automatic emergency calls etc.;
– **services using OBU interconnection with vehicle electronics,** allowing toll payments depending on vehicle operating parameters (e.g. current emissions production, driving style etc.);
– **services using surveillance system,** including detectors and cameras, which allow for example search for stolen vehicles, sectional control of vehicle speed, dangerous cargo transport control, identification of potentially overloaded vehicles etc.

It follows that the electronic toll system represents a basic platform for a wide range of telematic services, depending on the OBU producers and infrastructure administrators which of them they will offer. Precondition for the implementation of add-on services is standardization of the systems [Čech 2012].

Conclusion

Each technological solution of electronic toll has its own characteristics, strengths and weaknesses, and therefore the setting and the expected **range of the toll network** must be taken into account when designing the system. For example, in dense urban areas the use of GNSS/GSM technology could cause problems with the reception of the position signal. Likewise, this technology can be quite unnecessary luxury if charging only a few transit highways. On the other hand, this system allows continuous on-line monitoring of equipped vehicles and thus of the traffic flow. In the case of interest, or co-financing by carriers, these aspects can override and a more expensive technology may be acquired, in this case the technology will allow more than just an electronic payment. If a decision is made to charge a larger part of the road network within a state, not just selected motorways, probably the DSRC technology will not be chosen, as it requires building of toll gates on all road sections between intersections. For these reasons, we can not say that any of the systems is better or worse, all electronic tolling systems have their strengths and weaknesses, as summarized in Table № 1.

Table 1

Strengths and weaknesses of basic electronic toll systems

SYSTEM	STRENGHTS	WEAKNESSES
DSRC	+ inexpensive, „light” OBU + 5,8 GHz standardization + widespread and verified technology + relative simplicity + suitable for linear routes + a possible option for manual toll payment	– expansion of the charged network only by building new toll gates – limited superstructural telematics – more RSE – both financially and technically unsuitable for a larger network or for a greater expansion of the network
GNSS/GSM	+ less RSE + more options of superstructural telematics + expansion of the charged network by modifying the software + suitable for a wider road network + real time vehicle tracking	– more complicated OBU – possible additional costs for dual system – GSM communication charges – GNSS signal issues at some places – more expensive on a limited network compared to the DSRC technology

The cost comparison of two main systems of DSRC and GNSS/GPS is presented in Chart № 1. Both technologies have certain **starting costs** that are lower in the case of DSRC (center simpler, no GSM communication charges). The total cost then increases with the growth of the toll network. DSRC system curve rises more steeply, since the major cost items in expanding network are expensive toll gates, while in the GNSS/GSM system the expansion can be performed by software updates. The costs of expansion are therefore lower in this case. At a certain point, which is not precisely defined and whose position depends on the data presented in the legend, the total cost of DSRC system is higher.

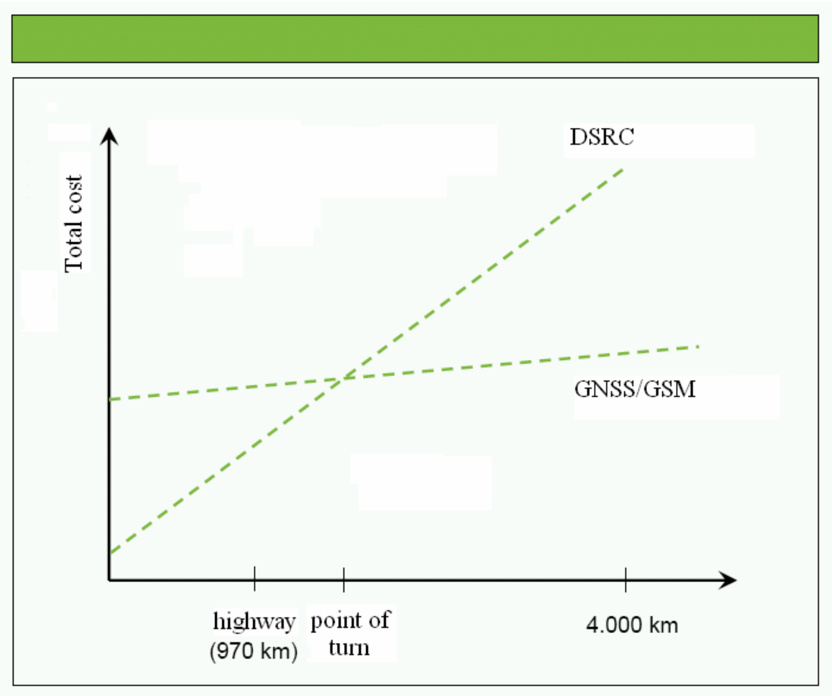

Chart 1. Economy of toll systems [Záklasník 2007]

Nevertheless, while deciding on the purchase of a toll system, not only the currently computed cost should be followed, but it is necessary to consider the properties of the system and state transport strategy for the next period, too. It should be noted that there are also other electronic toll systems, such as a unique Swiss concept of statewide charging (LSVA), or systems based on the optical-electronic number plate recognition (ANPR). However, their description is beyond the scope of this study.

Electronic toll collection systems represent in any case a new, modern form of charging for road transport routes. Their key advantage is the possibility to use this platform for add-on telematic applications, and their free-flow conception, allowing uninterrupted driving on toll road, unlike the manual toll collection.

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Abstract

The study deals with the use of information technology for road pricing. It characterizes the basic technological solutions of electronic fee collection systems, it specifies their technical attributes and it gives examples of their use in practice. A special part of the study is devoted to add-on telematic applications. Finally the two main fee collection systems are compared and their strengths, weaknesses and also the economic aspects are pointed out.

Key words: on board unit (OBU), toll gate, satellite positioning of vehicles, superstructural telematic applications.