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THE NATIONAL AUTOMATIC TOLL COLLECTION SYSTEM FOR THE REPUBLIC OF POLAND

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The paper refers to some problems of worldwide applications in electronic toll collection systems for motorways and expressways. According to Directive 2004/52/EC, these systems should 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. Authors have analysed the systems, which meet these requirements, especially the states as follows: The United States of America, Japan, Taiwan, Australia, Austria, Czech Republic, France, Norway and Germany. As a result of the analysis, it has turned out that only system using satellite positioning technology and mobile communications (GSM/GPRS) is the best toll solution of unique capabilities and this kind of technologically sophisticated system should be implemented in Poland. Author will present the initial structure of GSM/GPS based Toll Collection System for Poland. This type of system has many advantages. The first one is absence of the need for new road infrastructure (gantries); 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 ability to adapt easily and quickly to changes in charge parameters (road classes, vehicle types, emission levels, times slots, etc.). The third advantage is the system's ability to support other value-added services on the same technology platform.

Keywords: *Electronic Toll Collection (ECT), microwave technology, on-board unit (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 program, 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. Some of the benefits of ETC include:

– fuel savings;
– reduced mobile emissions by reducing or eliminating deceleration, waiting times, and acceleration;
– possible reduced drain on public monies, if the system is more self-sustaining or if the system was built/run via a public-private partnership arrangement.

The EC's target is for all vehicles to be equipped with an ETC box, linked to a standard contract for the owner/operator. At the end of each billing period, a single invoice would be issued, covering journeys through any of the member states.

All new electronic toll collection systems brought into service on or after the 1st of January, 2007 shall, for carrying out electronic toll transactions, to 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 above mentioned conditions are included in Directive 2004/52/EC of the European Parliament and of the Council of the 29th of April, 2004 on the interoperability of electronic road toll systems in the Community [4].

The requirements of that directive will be implemented in Poland based on the Act from the 28th of July, 2005 on changing act of public roads and some other acts [11]. It stressed that toll collecting charge institutions should be able to carry out electronic toll transactions from the 1st of January, 2011 – to the carriage of goods where the maximum permissible mass of the vehicle, including any trailer, or semi-trailer, exceeds 3, 5 tons, or of passengers by vehicles which are constructed or permanently adapted for carrying more than nine persons including the driver.

New electronic toll systems brought into service after the adoption of this Directive should use the satellite positioning and mobile communications technologies.

The Working Group No 1 (WG1) of Technical Committee 278 (Road Transport and Traffic Telematics) established in 1991 is responsible for electronic toll collection systems in European Union. ISO/TC 204 is the partner of CEN/TC 278 in ISO, responsible for the international standardisation of transport information, communication and control systems.

It is recommended to implement National Automated Toll System for highways and expressways in Poland. Authors have carried out the analysis of some systems functioning all over the world to choose the best one for Poland.

2. Characterization of Electronic Toll Collection Systems

A toll collection system 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.

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 systems were implemented in some countries between 1980 and 1990. These mentioned kinds of the systems equipped with automatic toll gates led to the use of devices intended to ensure that users were making correct toll payments for the type of vehicle they are driving. These included devices, which examine each vehicle before they entered the tollgate and while in the tollgate (for example, vehicle classification systems).

Since 1990's DSRC systems have presented new opportunities for users to make toll payments without the need for any physical contact with a toll collector or roadside equipment and without vehicles having to stop.

The Rationale for Electronic Toll Collection ETC systems take advantage of vehicle-to-roadside communication technologies (traditionally via microwave or infrared communication, more recently via GPS technology) to perform an electronic monetary transaction between a vehicle passing through a toll station and the toll agency.

Electronic Toll Road Systems in USA and some European Member States using microwave technology have functioned independently. The telematics systems are implemented in some states, an example being Hitachi System (Japan), as well as Barouh System (Taiwan), which provide the function of electronic road toll for highways and expressways and additionally function of transferring data from digital Tachograph. Toll Collecting System in Germany is a modern solution for the mentioned scope.

2.1. Electronic Tall Collection Systems Using Microwave Technology – DSRC

Electronic Toll Collection System using microwave technology is an element of Intelligent Transport Systems (ITS) that allows for non-stop toll collection and traffic monitoring. It is to uniquely identify each vehicle, electronically collect the toll, and provide general vehicle/traffic monitoring and data collection. New technologies and infrastructures provide the necessary capabilities for future applications such as incident management, alternate route guidance, and travel demand management. Properly implemented, system can reduce congestion, increase operating efficiency, improve travel time, reduce pollution, and improve safety of the roadway facility and surrounding corridors. All electronic tall systems using microwave technology all over the world have the same structure, which utilizes vehicles equipped with transponders (electronic tags), toll and control gantries, in-road/roadside detection and classification sensors, computerized system (hardware and software) and wireless communication (5,8 GHz nearly all over the world, only 5,9 GHz in USA), as well as enforcement technologies.

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. The antennas carried by gantries communicate with transponders (On Board Units, OBU). Users can get the OBU at a high number of points of sale 24 hours a day. OBU is equipped with a switch for the change of the vehicle class, for instance, in case of an additional trailer.

In June 2002, ASFINAG (Autobahnen und Schnellstrassen-Finanzierung AG) Austria's national road authority charged with planning, financing, building and maintenance of the highway network, awarded a contract for the installation and operation of a fully electronic nationwide toll system for heavy goods vehicles with a maximum permissible laden weight of 3, 5 tons to Autostrade S.p.A. with Kapsch TrafficCom AG [1] as the turn-key system supplier.

Figure 1. *Electronic transponders mounted on the vehicle's windshield*

The toll system is an open system with one gantry for toll communication in each sector between exit/entry-points (Fig. 2). More than 800 gantries (420 for each driving direction) has been implemented in the entire network. Users who drive on the tolled road network rarely can choose to pay the toll using the pre-pay procedure. This procedure is similar to that of a prepaid telephone card; the user charges the Go-Box with toll credit up to a certain maximum limit and the toll is then deducted from this credit as required by the toll system. According to this procedure, the owner of the vehicle registers with the system and provides an authorized means of payment, which is later used to pay the toll as required. The money is collected by the relevant card issuer (Maestro card, petrol card or credit card).

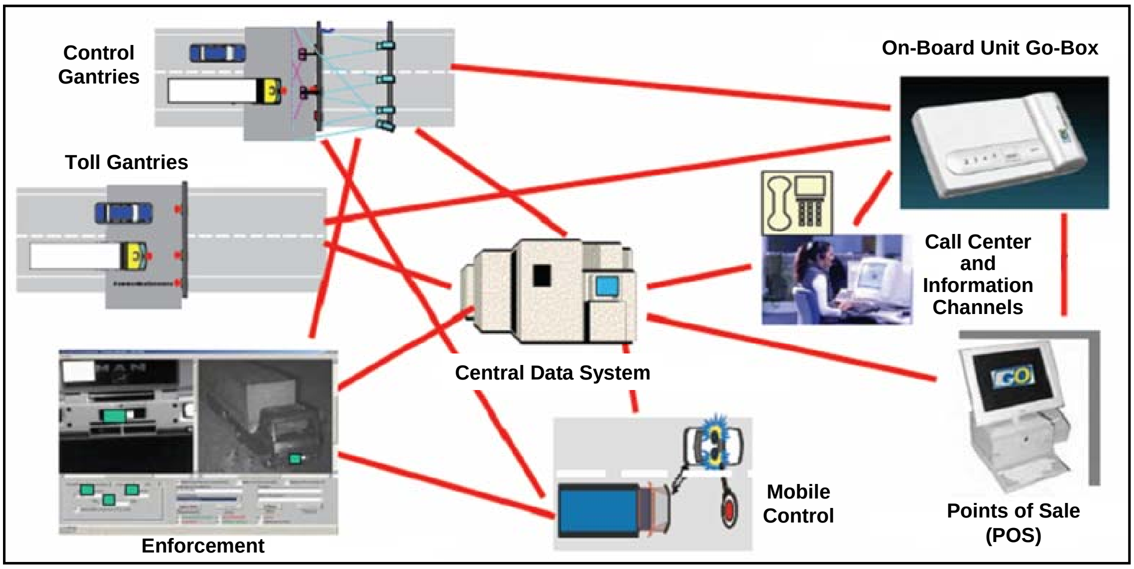

Figure 2*. An example of Electronic Toll System in Austria* [7]

Toll-enforcement which is one of the most important parts of an electronic toll system without barriers executed on the one hand by stationary toll-enforcement-gantries and portable enforcement equipments and on the other hand by a mobile control unit ("toll-enforcement-officers"). 100 permanent enforcement gantries are spread over the network primarily in the parts of higher traffic density. They consist of equipment for automatic vehicle classification by laser scanner. Vehicle class video cameras take a picture of the vehicles front. The license plate is then read by automatic character recognition and sent to the enforcement office.

Electronic toll has been paid by vehicles weighing 12 tons and more on 970 km of motorways and express roads in the Czech Republic as of January 1, 2007. Kapsch TrafficCom AB contracted the system in Czech Republic, but the transponder is different and called Premid. It is the brand name for a product line of microwave-based communication links for dedicated short range communication, DSRC, between fixed Roadside Equipment and mobile units. Kapsch TrafficCom AB has supplied this DSRC Link technology to a large number of traffic applications in over 20 countries all over the world.

The third generation of the system, Premid, is compliant with the current European CEN TC278 standards for Dedicated Short Range Communication, DSRC, as well as to the international ISO standard for Electronic Toll Collection (ETC).

The term TIS-PL refers to the new French electronic toll system for class 3 and 4 HGVs. Modelled on the "Liber-t" system designed for light vehicles in France, the TIS-PL is a badge which is fitted to the windscreen and which simplifies toll payments (motorways, tunnels, bridges etc.). Launched at the beginning of 2007, it has since replaced the CAPLIS toll card as the method of toll payment in France.

AutoPASS is an electronic toll collection system used in Norway. It allows collecting road tolls automatically from cars. It uses electronic radio transmitters and receivers operating at 5.8 GHz (MD5885).

The system involves the installation of a radio transmitter on the windscreen of a vehicle, and signing an agreement with one of the toll collection companies in Norway. Tolls are charged at toll plazas as before, but cars can drive past in up to 80 km/h. The system is administrated by the Norwegian Public Roads Administration. 23 of the 45 toll roads in Norway use the system, in addition to tests for use of the system on some car ferries. The primary reason that some projects don't support AutoPASS is that they charge both for the car and for passengers, which the system cannot support. All projects using AutoPASS can only charge per car. All systems with AutoPASS also have manual payment methods, though not necessarily manned.

The tolls in the United States are typically collected using RFID (Radio Frequency Identification). It is an automatic identification method, relying on storing and remotely retrieving data using devices called RFID tags or transponders. An RFID tag is an object that can be attached to or incorporated into a product, animal, or person for the purpose of identification using radio waves. Chip-based RFID tags contain silicon chips and antennae. Passive tags require no internal power source, whereas active tags require a power source.

Example of mentioned system is the E-ZPass electronic toll collection system used on most toll bridges and toll roads in the eastern U.S. from Virginia to Maine, and recently extended into Illinois; Houston`s EZ Tag, which also works in other parts of the state of Texas, California's FasTrak, Illinois` I-Pass, Florida’s SunPuss, and more recently Indiana’s I-Zoom (Fig. 3). Traffic in these special lanes can move well with minimal slowing. Toll roads have been only in 26 states as of 2006. The majority of states without any turnpikes are in the West and South [2, 5].

***Figure 3**. Types of ETC Systems in USA*
Based on – http: www.transcore.com

Operation principle of the system is the same in Europe (Fig. 4). As a car approaches a toll plaza, the radio-frequency (RF) field emitted from the antenna activates the transponder. The transponder broadcasts a signal back to the lane antenna with some basic information. That information is transferred from the lane antenna to the central database. If the account is in good standing, a toll is deducted from the driver's prepaid account. If the toll lane has a gate, the gate opens. A green light indicates that the driver can proceed. Some lanes have text messages that inform drivers of the toll just paid and their account balance. If the vehicle does not have a transponder, the system classifies it as a violator and cameras take photos of the vehicle and its license plate for processing. If the license plate is registered as belonging to toll system user, the account is debited only the toll charge, and no penalty is charged.

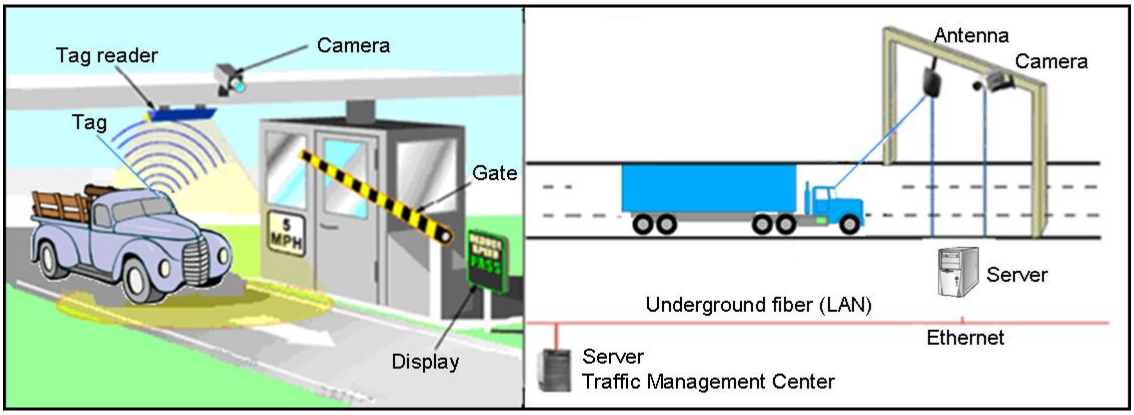

Figure 4. *E-ZPass System* (*on the left – closed road line, on the right – open road line*)
Based on – http://www.garamchai.com/askadesi/ask13.htm; http://www.calccit.org/itsdecision/serv_and_tech/list.html

E-ZPass tags are battery powered RFID transponders; they communicate with reader equipment built into lane-based or open road toll collection lanes. The most common type of tag is mounted on the inside of the vehicle's windshield behind the rear-view mirror. Some vehicles have windshields that block RFID signals. For those vehicles, an externally-mountable tag is offered, typically designed to attach to the vehicle's front license plate mounting points. Most E-ZPass lanes are converted closed toll lanes and must have fairly low speed limits for safety reasons (5 and 15 mph are typical). In some areas, however (typically recently built or retrofitted facilities), there is no need to slow down, as E-ZPass users utilize dedicated traffic lanes ("Express E-ZPass") outside the toll booth (Delaware Route 1, Virginia's Pocahontas Parkway, the Garden State Parkway’s express lanes, and the Pennsylvania Turnpike’s Warrendale and Mid-County (I-476) Toll Plazas).

The E-ZPass Interagency Group (IAG) was formed in 1990 with three states (NY, NJ & PA) and seven agencies. The first deployment of E-ZPass was on the New York State Thruway at the Spring Valley barrier on August 3, 1993. The IAG currently has over 9 million account holders who utilize more than 16 million transponders operating electronic toll collection for 23 agencies in 12 states. The nine million account holders reside throughout North America with thousands in each state and province including the States of Hawaii and Alaska.

Another system in the USA is FasTrak. It is used state-wide on all of the toll roads and bridges along the California Freeway and Expressway System.

Like other ETC systems, FasTrak is designed to eliminate the need for cars to stop to pay at toll booths, thus decreasing the traffic traditionally associated with toll roads. Its use of technology to improve transit is in line with the U.S. Department of Transportation's Intelligent Transportation Systems initiative.

FasTrak uses RFID technology to read data from a transponder placed in a vehicle (usually mounted by Velcro strips to the windshield) moving at speeds that may exceed 70 mph. The RFID transponder in each vehicle is associated with a prepaid debit account; each time the vehicle passes underneath a toll collection site, the account is debited to pay the toll. If a vehicle does not have a transponder, the system uses automatic number plate recognition to take photos of the vehicle and its license plate for processing.

Anybody with a FasTrak transponder can use it to pay tolls on any California toll road or bridge using the system. But people are encouraged to open their accounts with the local agency in charge of the toll facility that they use the most. Different agencies may offer different discounts and incentives, and people may be charged a fee if the majority of their FasTrak use occurs elsewhere.

SunPass is an electronic toll collection system in use by the State of Florida and has been originally created by the Florida Department of Transportation's Florida's Turnpike Enterprise. The system uses

Amtech active RFID windshield-mounted transponders manufactured by TransCore along with lane equipment designed by several companies including SAIC and TransCore. SunPass is fully interoperable with E-Pass (from the Orlando-Orange County Expressway Authority), O-Pass (from the Osceola Parkway), LeeWay (from Lee County toll bridges) and Miami-Dade Expressway Authority (MDX) toll roads. SunPass may also be used at the Orlando International Airport to pay for parking. There are plans for other major Florida airports to utilize the SunPass system for parking fees.

SunPass-Only toll lanes on most toll roads in Florida allow a vehicle to proceed through the tollbooth at speeds of up to 25 mph (40 km/h). This is a safety guideline, not a technological limitation, and violation may be a subject to a speeding ticket and associated fine. Some mainline toll barriers are being constructed with wider SunPass-Only lanes that can handle speeds up to 50 mph (80 km/h). E-Pass-Only lanes system have a speed limit of 35 mph (60 km/h), though the mainline toll barriers will all have dedicated lanes capable of full-speed automatic toll collection at up to 65 mph (105 km/h) by 2009.

I-PASS is the Illinois Tollway's Electronic Toll Collection Program. Users of the Tollway are encouraged to open an account that allows them to travel through the toll plazas faster, in many cases without having to stop, and to avoid having to handle cash toll payments.

Hitachi has developed creative solutions to roadside communications, traffic operation and payment processing to enhance toll collection system performance (Fig. 5). Capable of high-speed operation to enable free traffic flow, the system incorporates a fully integrated payment processing system, comprising facilities to identify and record illegal passage, efficient management of toll-collection data, system auditing and access management for high security and EDI processing to facilitate smooth fund transfers.

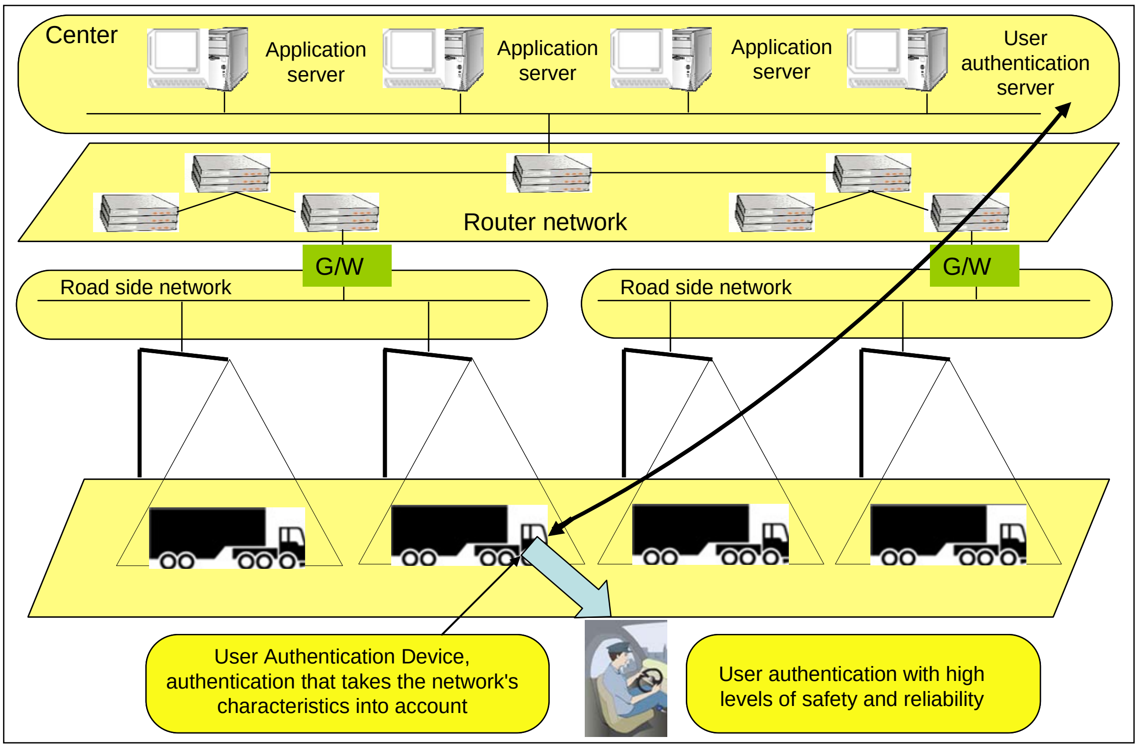

Figure 5. *The project of electronic toll collection system created by Hitachi and supported by Telecommunications Advancement Organization of Japan*
Based on – http://www.hitachi.co.jp/en/products/its/product/solution/2004613_12384.html

Hitachi covers everything from data collection to information delivery. Hitachi has made advanced system concepts a reality, with a complete information system consisting of data collection, information management, on-board equipment, radio beacons and other facilities.

This system, developed to improve both safety and convenience levels, not only provides accident and other travel-related data to cars driving at high speeds, it also uses the Internet to provide music and image streaming, and to reserve and pay for airline tickets.

Fibre-optic cables buried within the road are capable of detecting road surface temperatures and can issue warnings when freezing conditions exist.

An image recognition system monitors your car as you drive to detect possible danger signs. It offers the driver information on the possible existence of dangerous situations, and provides information on safer driving to avert such dangers.

Microwave-based digital short range communication (DSRC) 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 majority of systems all over the world have tags reading-only, contain a fixed identification code which, when interrogated by a roadside reading device at the charging point, conveys this identity to the roadside system.

China has got currently ETC systems in Guangdong Province, Beijing, and Shanghai [13]. Although several DSRC systems have been developed and used in China, they use different frequency bands and thus are not compatible with each other. To solve this problem, the Chinese Government has determined the domestic standardization of the 5.8 GHz-band (GB/T 20839-2007, GB/T 20851.1, 2, 3, 4, 5. 2007), which indicates that this frequency band will be adopted as the standard for the DSRC systems in China.

Research is underway on a new generation of electronic highway toll collection technology, based on GPS and wireless communication technology to implement such a system in China. For the reason of aforementioned system, China has planned to develop a truly global satellite navigation system, known as Compass or Beidou-2. The current Beidou-1 system (made up of 4 satellites) is experimental and has limited coverage and application. The new system will be a constellation of 35 satellites, which include 5 geo-stationary orbit (GEO) satellites and 30 medium Earth orbit (MEO) satellites that will offer complete coverage of the globe. There will be two levels of service provided; free service for those in China, and licensed service for the military.

The free service will have a 10 meter location-tracking accuracy, will synchronize clocks with an accuracy of 50 ns, and measure speeds within 0.2 m/s.

The licensed service will be more accurate than the free service, can be used for communication, and will supply information about the system status to the users.

Two satellites for Beidou 2 have been launched in early 2007. In the next few years, China plans to continue experimentation and system set-up operations.

By the end of 2020, China will have finished constructing 12 roads and formed the main arteries of state roads with high-grade highways, which will run through capital, cities directly under the jurisdiction of state, the capitals of each provinces and municipalities.

The Taiwanese Electronic Toll Collection System is composed of four subsystems as follows: roadside sub-system, vehicle sub-system, administration sub-system, and external sub-system [3].

The roadside sub-system is composed of several Changeable Message Signs (CMS) and Surveillance Station (SS) – Fig. 6. The primary function of CMSs is to provide travel information to truck drivers, and they are directly controlled by the Central Surveillance Centre (CSC). The SS, which is installed at the main line of highway is controlled by the nearest downstream Vehicle Weigh Control Centre (VWCC).

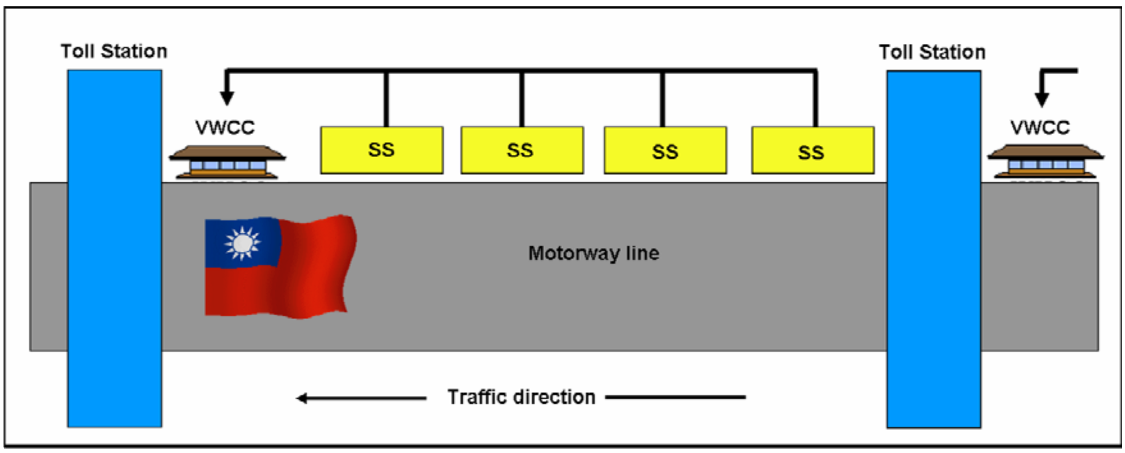

Figure 6. *Roadside sub-system of ETC in Taiwan*

The SS consists of five units as follows:

- Weigh-in-Motion (WIM) system. This system detects the speed, gross vehicle weight, axle number, and axle distances of each passing truck. All WIM collected data are transferred immediately to the Roadside Operation Computer (ROC).
- Roadside Unit (RSU). The main function of this unit is to communicate with the OBU on the vehicle. The communication between the RSU and OBU uses the DSRC to identify each passing truck. The ETC transaction and the notification of the results of weight and safety record check can also be done through the DSRC. Since most of the vehicles pass the WIM and RSU at a relatively high speeds (e.g. 90 to 100 km/h), two RSUs are needed for each MSS. The second RSU is located about 100 m downstream and is used to send the check results back to the driver.
- Automatic Vehicle Classification (AVC). The AVC is designed to detect the classification of each passing truck. The loop detectors of the WIM can be used in AVC. By comparison between data from the AVC and from the RSU, any possibility of miss-using the OBU by truck drivers will be identified and reported immediately.
- Vehicle Enforcement System (VES): The VES will automatically catch the image of any violating vehicle that is reported by the SS. Not only the vehicle weight check but also other vehicle safety related issues, such as inspection and insurance, are checked by the whole system. Although the WIM cannot be used for law enforcement directly, the image is still transmitted to the VWCC for the possible citation latter. However, the driver will then be notified by the OBU through the data transmitted from the second RSU.
- Roadside Operation Computer (ROC): All data and information from the above units are gathered here. The ROC serves as the data processing and transferring bridge between the VWCC and other MSS units.

OBU is the major component of the vehicle sub-system. With the use of OBU, the ETC transaction and truck weight and safety record check can then be processed. The OBU must be capable of displaying “red” and “green” lights on the small LCD screen or providing different sounds to indicate the various checking statuses to drivers.

The administration sub-system is composed of the Vehicle Weigh Control Centre (VWCC) and Central Surveillance Centre (CSC). This system controls all the following sub-systems and the upstream SSs. The computer system controls the static weight pad, truck record checking sub-system, violation citation sub-system, traveller information sub-system, and fleet management sub-system. Under current freeway traffic control regulations in Taiwan, all loaded trucks must enter a weigh station that is located in both sides of each toll station for weight checking. The CSC is comprised of the truck surveillance sub-system, weight analysis sub-system, and traveller information sub-system.

The External Sub-system. The external sub-system is comprised of the truck company’s surveillance computer, the DMV (Department of Motor Vehicles) computer, and the traveller information service provider.

2.2. GPS/GSM Based Tall Collection Systems

Hitachi telematics system was implemented in Japan in 2001 for managing of transport companies [6]. It functions based on GPS, GSM communication and Internet. Each vehicle is equipped with digital tachograph, OBU and telematics terminal, which uses GPS to measure its current position and reports it to an application service provider (ASP) centre at regular intervals (usually every 15 minutes) via a mobile packet transmission network. A PC (personal computer) at the transportation company’s office can be connected to the ASP centre via the Internet, and can be used to display the current position and route of each vehicle superimposed on a map of Japan. Hitachi’s ASP service can be linked to a toll collect system, allowing the fleet managers to respond precisely to enquiries from consignors about their payment for highways and expressways. In Hitachi’s truck fleet management service system, the telematics terminals collect the types of data (speed, time, distance and charge of road), and transmit it to Hitachi’s ASP centre via a mobile packet transmission network. The driving data collected in this way can be freely inspected and amended via the Internet, and can be used to print out documents such as daily driving reports and monthly statistical reports, or downloaded into accounting/payroll systems. It is also possible to identify bad driving habits such excessive acceleration or braking, speeding or prolonged idling, and this information can be used to make the drivers safer and more fuel-efficient by providing them with suitable feedback.

The trucks are fitted with telematics equipment, GPS systems, packet cell phone terminals, etc., and thus have the potential to be used as floating cars. First, the truck positional data is superimposed on a map to infer the route on which the truck is travelling, and then the speed of the truck along this route is calculated. Next, this data is statistically processed to calculate the estimated arrival time. To avoid excessive communication costs, the time intervals at which this positional information is uploaded should be made as long as possible. However, this makes it harder to track the routes travelled by the trucks.

Japan has started a new project of Quasi-Zenith Satellite System (QZSS) in FY2003 [12]. QZSS consists of three satellites and will provide a regional satellite positioning service as well as communication and broadcasting services. Each satellite is in three different orbit planes, which are obtained by inclining the geo-stationary orbit (GEO) by about 45 degree. In this system, at least one satellite stays around the zenith for about eight hours and is visible with a higher elevation angle in mid-latitude area (e.g. at least 80 deg. in Tokyo) than in case of using a satellite in GEO. This characteristic is very beneficial in large cities where there are many tall buildings which block the signal from satellites in GEO. Thus, satellite availability for satellite positioning and mobile communication services is expected to be greatly improved.

The QZSS satellite positioning system is planned to be compatible and interoperable with the civil specifications of modernized GPS except its orbit and some experiments, and will compliment and augment the GPS. The aimed accuracy of GPS-QZSS time offset is less than 3 ns rms over any 24-hour period.

Taiwanese telemtaics system (Fig. 7) has the same structure as Hitachi one. It is capable of calculating and collecting road use charges via OBU and GPS. Furthermore it allows Baoruh Digital Tachograph to send vehicle status and position to the backend server via GSM/GPRS, while the server is capable of issuing commands or system parameters simultaneously. To use GIS technology to provide best route-analysis, distance measurement, route management and restrictive access settings, road speed limit. All types of reports can be directly printed out or transformed into other file formats, such PDF, Excel, html, CSB, text file [10].

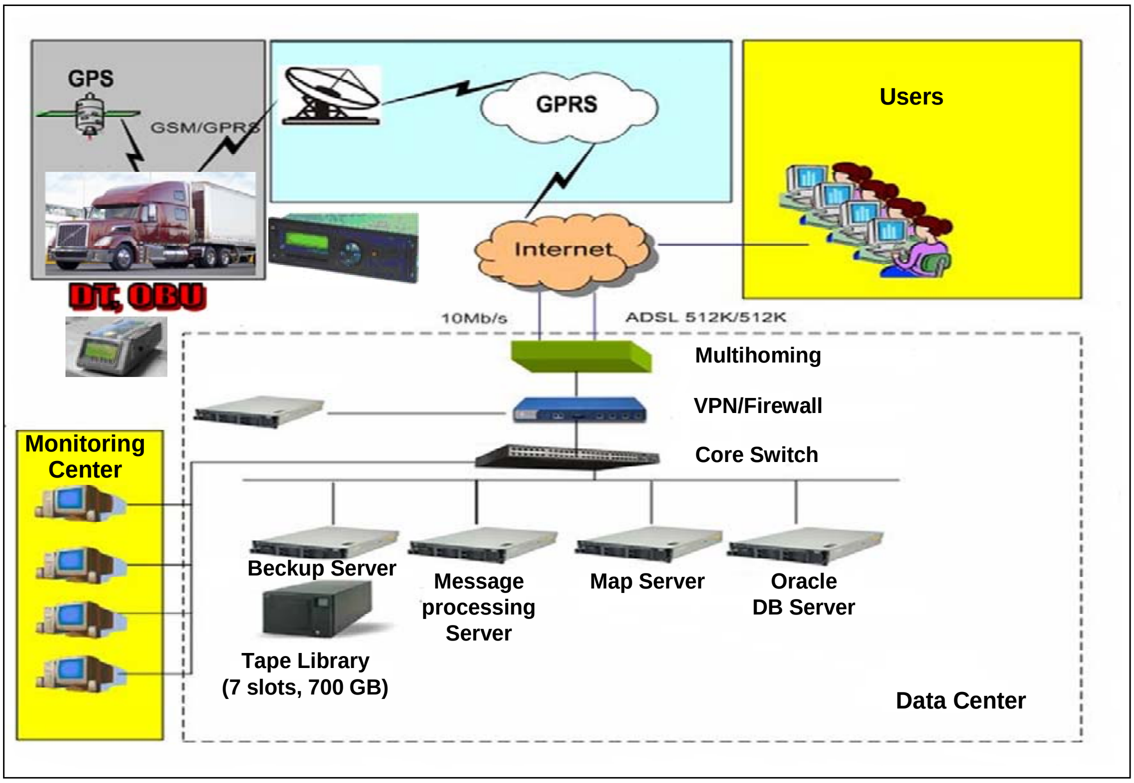

***Figure** 7. The structure of Taiwanese telemtaics system*

In January 2005 the Toll Collect system was introduced on the 12 000 km of German highways for all trucks with a maximum weight of 12t and above. Its technology is based on the GPS, and a web application (GSM). System is capable of calculating and collecting road use charges based on the distance travelled.

In addition, the Toll Collect system ensures that the collection of road tolls does not disrupt traffic flow. In contrast to conventional toll systems, Toll Collect does not require vehicles to slow down or stop, or restrict them to a designated lane [8].

The main element of the automatic log-on system is the On-Board Unit (Fig. 8). OBU is used for positioning, monitoring and billing. With the aid of GPS satellite signals and other positioning sensors, the OBU automatically determines how many kilometres 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 Toll Collect computer centre for further processing. Additionally the OBUs have infrared interfaces for communicating with stationary control bridges on the motorways. System has 300 gantries equipped with IR detection equipment and high resolution cameras able to pick out trucks via profiling (and record number plates). These send a DSRC signal to a DSRC transponder (which is a part of the OBU) in the lorry to check on the accuracy of the GPS as a back-up and also alert BAG officers to toll violations.

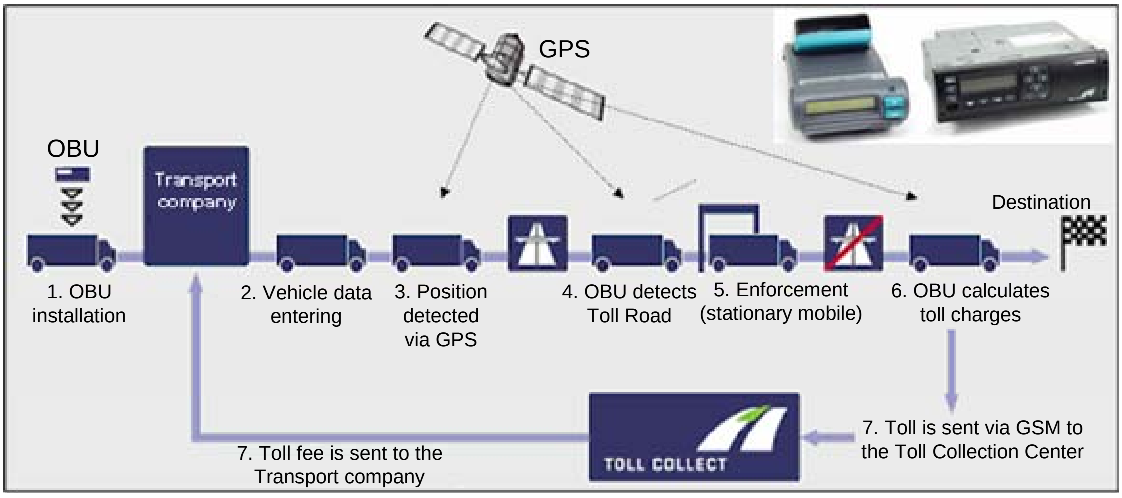

Figure 8. *Toll Collect System in Germany – automated logging* [*9*]

Toll Enforcement will also rely on mobile patrols, consisting of a fleet of 300 vehicles with 540 officers of the Federal Office of Freight (BAG). The officers will patrol the autobahns, checking vehicles and drivers to see if they have paid the toll or have the OBU installed (these vehicles will be equipped with an infrared short range DSRC (Dedicated Short Range Communications) system that can be used to scan and monitor trucks in motion). The BAG will have police powers to request trucks to stop for examination at any point during their journey. The OBU will also be able to work with the new Galileo satellite system for positioning which is being developed in Europe as a more accurate alternative to GPS.

Electronic Toll Collection System was implemented in Australia, especially in Melbourne and Sydney. The company Transurban was awarded the contract to construct two new freeways – labelled the Western and Southern Links – directly linking a number of existing freeways to provide a continuous, high-capacity road route to, and around, the central business district.

When electronic toll collection or ETC was introduced to Australia starting in the mid 1990's there were already several competing technologies world-wide and two incompatible systems were introduced by different operators of toll roads in east coast states of Australia. It was soon apparent that this would limit the take-up of the technology, so in 1998 the governments of Australia decided to adopt the European CEN Standard for all future projects. Despite this, interoperability was not immediately achieved and a standardization committee was formed to examine interoperability between the different suppliers' products. The result was Australian standard AS 4962 published in 2001.

D. Hensher, Director of the Institute of Transport Studies at the University of Sydney (Australia), has offered a new electronic toll collection system, based on distance and axle load (Fig. 9).

Tolls based on axle loads can be used to charge heavy vehicles for road damage. Heavy vehicle operators ignore both road damage and congestion costs, imposed on others. A heavy vehicle also contributes more to congestion than a car, because of its size and slow acceleration in stop start conditions.

Damage to roads rises faster than linearly with payload per axle, yet fuel consumption rises less than linearly with payload, hence, fuel taxes are quite inappropriate for capturing road wear costs and for encouraging efficient practices.

Distance-based charges system may consist of the following.

- Participants in tracking/distance reckoning and road use assessment system: the vehicle, the station (be it a service station or a truck station or other).
- Tracking can be defined spatially with using OBU (on-board unit) and GPS system.
- OBU records distance in jurisdiction.
- Central computer: wirelessly intercommunicating with OBU, calculates road-use charge and applies it at point of sale, once the charge has been paid the system turns OBU back to zero, re-initiating the road-user charge procedure.

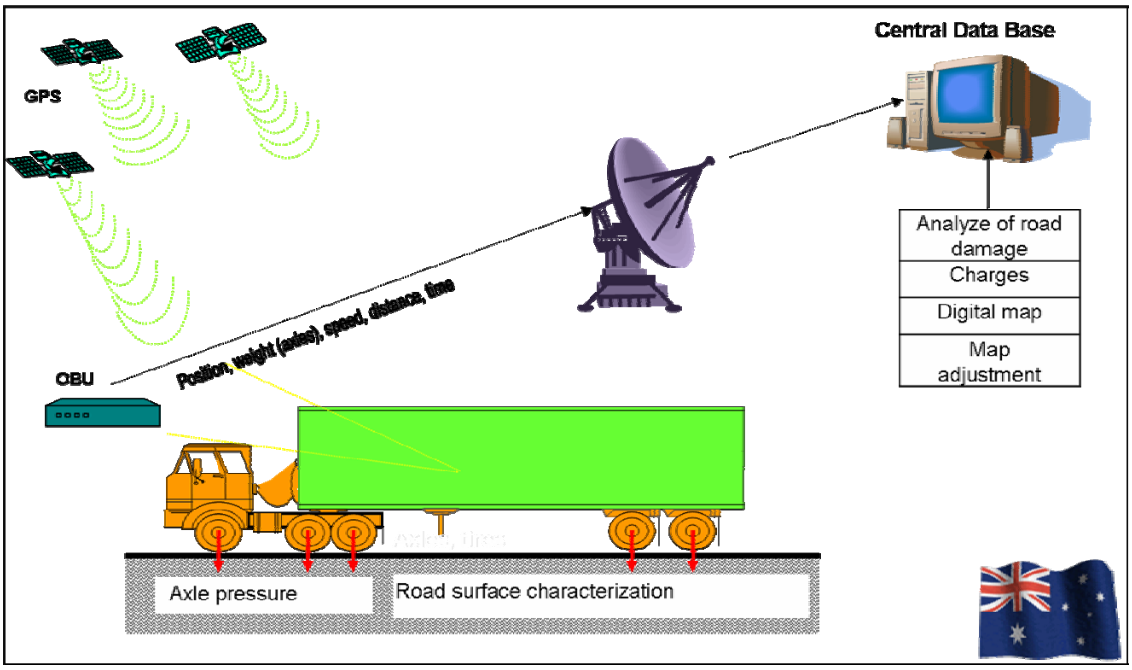

Figure 9. *Proposition of ETC system for Australia*
Based on presentation – Hensher D. A, Road User Charging: Where to Next. ALGA National Local Roads and Transport Congress, Launceston – http://www.alga.asn.au/policy/transport/congress/2005/presentations/hensher.php

In a field test in Melbourne and the New South Wales region, Siemens ITS, Transurban, the toll solutions market leader in Australia, and the largest Australian mobile radio provider, Telstra, have successfully tested a hybrid OBU from Siemens VDO and a new software application with which both microwave-based and satellite-based toll solutions can be used by one single unit.

The hybrid OBU, into which a DSRC microwave module is integrated, makes it possible to detect existing microwave signals from toll gantries in addition to normal satellite operation. Therefore, Siemens is the first manufacturer of a hybrid OBU which detects microwave signals from gantries and processes GPS signals. This is above all important in view of possible migration from DSRC to GPS solutions.

A GSM/GPS system for road charging has been made a long-term government target in the UK. This technology is the only ETC system that can also potentially support telematics services, including the e-call provision that the EC would like to see introduced for all new cars from around 2010.

3. Future Trends of Electronic Toll Collection Systems

Specialist literature study demonstrates that Europe already has a poor record on the interoperability of ETC services between different countries. Each nation has hitherto developed its own system for toll collection, with at present only one example of cross-border co-operation. A future single contract and invoice system would have to take into account the split between public and private toll operators and the national differences in areas such as tariffs, sales tax and legislation.

Electronic Toll Collection (ETC) systems offer the possibility of charging road vehicles in a more flexible way and allow infrastructure charging policies to be implemented. It is vital for such systems to be interoperable across national borders to avoid creating new obstacles to traffic flow in Europe. Interoperability should therefore enable users to travel throughout the Union without charging procedures changing from one country to another and without having to install extra equipment to access other charging zones. This does not mean there would be one single supplier but that there should be sufficient technical compatibility between different systems so that paying charges on different stretches of road in the Union would be a seamless operation. Interoperability is, therefore, an important factor from the viewpoint of the single market, transport policy and the development of the information society.

This Communication examines the obstacles to interoperable electronic fee collection systems and puts forward certain recommendations for arriving at an appropriate level of interoperability on a European scale.

The first major issue studied is technical interoperability. Existing motorway ETC systems make use of Dedicated Short Range Communication (DSRC) between fixed roadside equipment and vehicles. Another type of system is based on satellite location (GPS) and mobile telephone technology (GSM).

The first step towards interoperability should be the definition of a common minimum level of functionality to enable authorized subscribers to pay fees using the same method of payment and the same equipment anywhere on the network of operators belonging to the system.

The second major issue is contractual interoperability. The existence of interoperable equipment needs to be accompanied by contractual agreements between infrastructure operators. The same concept of a common minimum level of functionality should therefore be applied.

The Commission argues that satellite positioning in conjunction with mobile communications is the only solution that allows easy application of ‘zone tolls’ – for instance, within conurbation.

In 2004 the agreement was signed between the United States of America and the European Community. The objective of it is to provide a framework for cooperation between the Parties in the promotion, provision and use of civil GPS and GALILEO navigation and timing signals and services, value-added services, augmentations, and global navigation and timing goods. The Parties intend to work together, both bilaterally and in multilateral for, as provided herein, to promote and facilitate the use of these signals, services, and equipment for peaceful civil, commercial, and scientific uses, consistent with and in furtherance of mutual security interests. This agreement is intended to complement and facilitate agreements in force, or which may be negotiated in the future, between the Parties related to the design and implementation of civil satellite-based navigation and timing signals and services, augmentations, or value-added services. There will be four different navigation services available:

- The Open Service (OS) will be free for anyone to access. The OS signals will be broadcast in two bands, at 1164–1214 MHz and at 1563–1591 MHz. Receivers will achieve an accuracy of < 4 m horizontally and < 8 m vertically if they use both OS bands. Receivers that use only a single band will still achieve < 15 m horizontally and < 35 m vertically, comparable to what the civilian GPS C/A service provides today. It is expected that most future mass market receivers, such as automotive navigation systems will process both the GPS C/A and the Galileo OS signals, for maximum coverage.
- The encrypted Commercial Service (CS) will be available for a fee and will offer an accuracy of better than 1 m. The CS can also be complemented by ground stations to bring the accuracy down to less than 10 cm. This signal will be broadcast in three frequency bands, the two used for the OS signals, as well as at 1260–1300 MHz.

The Transport Council reached historical conclusions at its session of 29/30th November, 2007 on the future developments of Galileo, more specifically on the procurement and governance aspects. Together with the ECOFIN Council and European Parliament decision of 23rd November, 2007 on the financing of the program, the European Commission has now the basis to implement the next phase of the European GNSS programs. As proposed by the Commission on 19 September, this next phase – the deployment of Galileo – will be carried out and financed by the Community. The next phase includes the operational availability of EGNOS within the next 1–2 years as well as the procurement of Galileo and leading to a Galileo operational system by 2013.

The Commission proposes that the use of satellite positioning technology should be compulsory as from 2008 for newly introduced systems, and as from 2012 for all systems. Systems brought into service before 1st January, 2008 will be required to have abandoned the microwave technology by 1st January, 2012.

With a view to the possible migration to systems based on satellite and mobile communications technologies from services based on other technologies, the Commission shall submit a report no later than 31st December, 2009.

4. System Proposition for the Republic of Poland

The Motor Transport Institute with University of Technology in Warsaw and Lublin intend to create the structure of The National Automatic Toll Collection System for Poland (NATCS). System will be consisted of The National Automatic Toll Collection Centre (NATCC), control gates and on-board units (OBU) – Fig. 10. The prototype of control gate and OBU will be carried out by AutoGuard S.A. It is a leading company on Polish market that produces telematics systems since 2000. 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.

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 kilometres 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 support with electronic road maps and data of users registered in as well as data charges of highways and expressways.

Charge counting will be started 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.

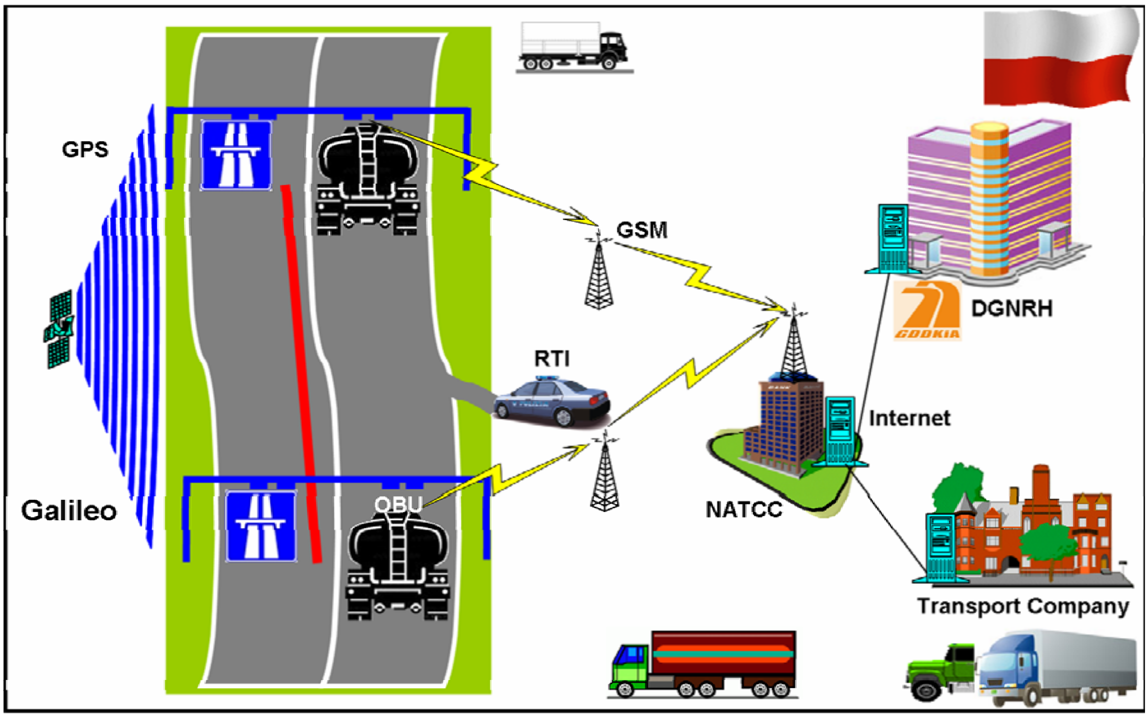

Figure 10. *The structure of the National Automatic Toll Collection System (NATCS)*

Details on Figure 4 to be clarified:

– DGNRH – Directorate-General for National Roads and Highways,
– NATCC – The National Toll Collection Centre,
– RTI – Road Transport Inspection.

For truck drivers, automatic log-on requires the least amount of effort: He is not required to book the route himself. All key data is already stored in the On-Board Unit. The prerequisite for participating in automatic log-on is registration the transport company and the trucks with General Directorate-General for National Roads and Highways (DGNRH) and pay toll to DGNHR. After registration, the company receives a vehicle card for each truck. This card contains the most important vehicle information. With this vehicle card, the user can schedule an appointment with an authorized Toll Collect Service Partner to have an On-Board Unit installed.

The simplest way to pay the truck toll is to register company and vehicles with DGNHR. A registered user can have an On-Board Unit installed and participate in automatic log-on and use all possible means paying the toll (credit account, credit card or fuel card, cash payment). Immediately after registering your company, you will receive a personal user number and a master PIN number for security. After vehicle registration, we will send you a vehicle card for each truck, containing the most important information about the vehicle.

System has control gates equipped with IR detection equipment and high resolution cameras able to pick out trucks via profiling (and record number plates) – Fig. 11.

Toll enforcement and the punishment of violations are the responsibility of the Road Transport Inspection. The RTI has provided with the technology needed for an effective enforcement system so that RTI can enforce correct booking of the toll, thereby ensuring that all toll payers are treated equally. With the aid of this system, RTI can determine if a vehicle is has an obligation to pay toll and if it has met this obligation fully, partially, or not at all.

The control system distinguishes between automatic enforcement through control gates, enforcement by stationary and mobile teams, and company-level enforcement. 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.

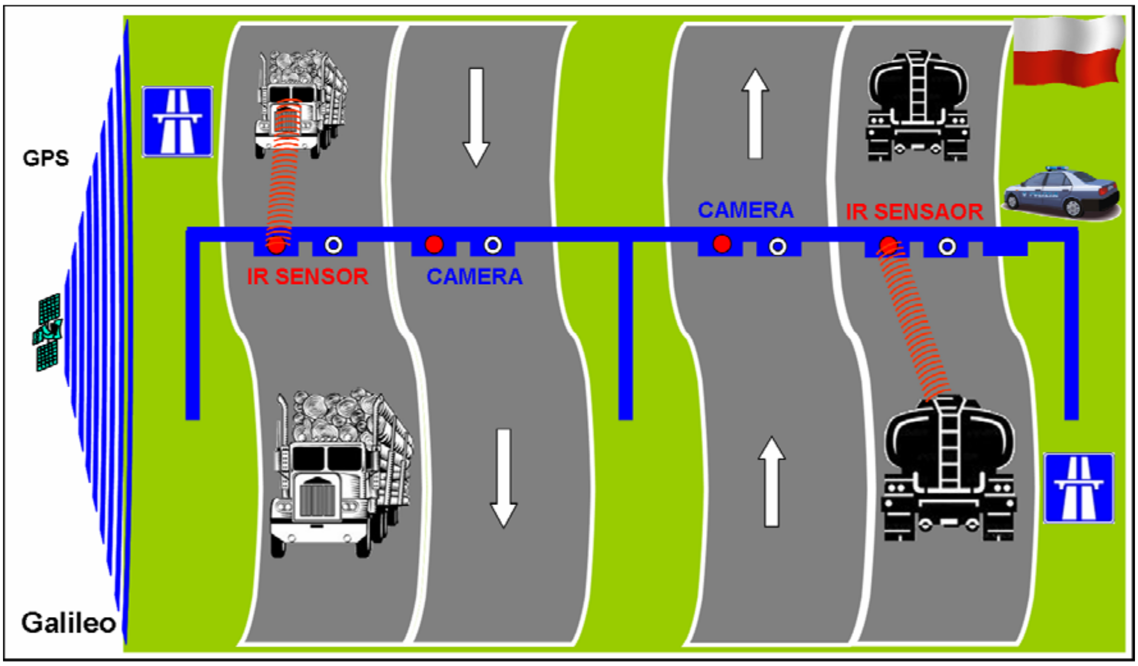

Figure 11. *Control gate with electronic equipment*

5. Conclusions

These mentioned families of technology for future electronic toll collect systems and all have different attributes, advantages and disadvantages. 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 absence of the need for new road infrastructure (gantries), operators can keep using the existing infrastructure. System works without toll booths, extra lanes, speed restrictions or complex structures along toll roads. The second is much greater flexibility in defining or changing payment by simply redefining the "virtual" toll areas. It means 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.

These systems were implemented in the Germany and Hong Kong and will be implemented in UK, India, USA, China, and Australia. 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.

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