Galileo and Communication Technologies – Benefits, New Applications and Future developments of the Intelligent Transport Systems

Dr. Oihana Otaegui, *VICOMTech*
Dr. Maria Teresa Linaza, *VICOMTech*
Ander Garcia, *VICOMTech*
Iván Jiménez, *VICOMTech*

BIOGRAPHY

Dr. Oihana Otaegui obtained her degree in Electronic Engineering in 1999 and a PhD in Telecommunication from the University of Navarra, Spain in 2005. From September 1999 and December 2003 she was a researcher in the Electronic department of CEIT in San Sebastian Spain. From January 2003 to May 2007 she was senior researcher of the Navigation department of Fraunhofer Institut IIS, Erlangen, Germany. She is member of VICOMTech since June 2007, assuming the position of Head of Transport, Logistics and GIS department.

Dr. María Teresa Linaza obtained her degree in Electrical Engineering in 1996 and a Ph.D. in Industrial Engineering from the University of Navarra, Spain in 2001. From September 1996 to December 2001, she was member of the R&D team in the Electronic and Communications Department of the CEIT research centre in San Sebastian, Spain. She is member of VICOMTech R&D team since January 2002, assuming the position of Project Manager.

Ander Garcia studied Telecommunications Engineering at the Engineering School of Bilbao, Basque Country University, between 1997 and 2002. In 2003 he started his PhD at the same university. Since 2003 he has been working in VICOMTech. During the last two years he has been involved in several national and international projects related to tourism, web 2.0, mobility and route creation. Since 2003 he has been an associated professor of subjects related to databases and software engineering at the Computer Science faculty.

Iván Jiménez obtained his degree in Computer Sciences at the Basque Contry University in 1997. From 1997 to 2002 he has work in several companies such as KUTXA, Technology Park Society and Hispavista as a programmer developing applications. Since 2002 he is at VICOMTech R&D team developing applications for Semantic Web Technologies, content management and retrieval, eLearning and Web technologies

ABSTRACT

This paper will analyse the design, development and implementation of a common flexible interoperable and easily extendable Electronic Fee Collection System (EFC) based on satellite positioning. This new tolling system will allow users to travel across Europe and pay for tolls using a single contractual system, avoiding queues at toll stations. Additionally, due to the nature of the overall scheme, other valuable outcomes, such as pay per use insurance services or real time traffic management systems will be obtained.

INTRODUCTION

During the last quarter of the 20th Century, there have been major technological advances in vehicle platforms and technological infrastructures. Connectivity and wireless communications between individuals and individuals- machine have increased dramatically.
The current EGNOS system and the forthcoming Galileo Satellite Navigation System will provide higher levels of service guarantee, integrity and availability which are key factors for developing new applications with high requirements in the Intelligent Transport area. Car navigators are already quite common, advanced driver assistance systems are being introduced, and the next logical step will be towards the creation and exploitation of differentiator factors provided by Galileo. Opportunities for improving Safety, increasing Traffic Management capabilities, providing Satellite-Based Tolling (Virtual Tolling) and developing any other innovative applications will be explored in the near future.
GALILEO in combination with new technologies such as GPRS, WIFI or UMTS will contribute to the development of a wide range of applications and services covering many economic activities and all segments of society. Road, rail, see and air transport will benefit from the hybridization of these technologies. The position accuracy will increase dramatically to the point where automatic guidance in all of the areas could be not only a dream but reality.
Nowadays, one of the most important applications of the navigation systems is remote services. Applications such as the electronic-fee-collection, truck fleet control or antitheft devices imply millions of users through the roads of the whole world. Particularly in Europe, with GALILEO system and the efforts of the European Parliament in prioritizing the toll collecting systems based on GNSS and cellular networks (GNSS/CN), appear as one of the key applications of the future. This application will be discussed deeply in the paper

analyzing the effects of the lack of coverage or the service interruptions due to disturbances on the satellite network arouse the implementation of a more reliable solution combining GNSS and autonomous navigation systems. This paper presents the way a GNSS/INS/WIFI integrated or hybridized system offers the accuracy and quality assurance required in remote services.

STATE OF THE ART

The first approach for satellite tolling is the German Toll Collect [6], which has been operational since the 1st of January 2005. The company is a consortium led by DaimlerChrysler and Deutsche Telekom which have patented the system under German patent document DE 44 02 613 A1. This new toll system, called LKW-MAUT, is a tax for trucks based on the distance driven in kilometres, number of axles and the emission category of the truck.

The toll system is not based on toll booths or plazas on the highways themselves but instead works via several methods: On Board Units (OBU), manual payment terminals and via the Internet. OBUs work via GPS and the on-board odometer or tachograph as a back-up to determine how far the truck has travelled by reference to a digital map, GSM is used to authorise the payment of the toll via a wireless link.

The main advantage derived from this system is that it has clearly demonstrated the reliability of toll systems based on satellite technology. Nevertheless, this system has some weak points as [4] addresses: "However this system is its own impediment especially because of its dual approach (manual and electronic). Such approach incurs high operating costs, which, at over 20%, are much higher than those of other existing system". Additionally, Toll Collect has been made overly complex in an attempt to solve inherent GPS-related shortfalls. The main problem lays on the use of GPS which suffers from two crucial weaknesses when used for secure applications such as electronic tolling systems: there is no contractual service guarantee (the system belongs to the US Department of Defence and can be switched off or suffer a signal degradation without previous notification), and, the GPS lacks integrity, which means that there is absolutely no guarantee that the GPS error might not sometimes be so big as to cause errors in the toll calculations. Studies conducted by the London Transport Authority [5], have shown that, although the GPS error is statistically very small nowadays (even below 10 m) there are still occasions when the error might be as big as 1000 m and it might quite often (1% of cases) be several tens of meters. In fact, the German system has been fitted with roadside devices to solve this error. These are redundant devices that make the system expensive and cumbersome to set up; they would also be unnecessary if the positioning system guaranteed integrity, something that is impossible today using GPS alone. Additionally there is another potential vulnerability in systems using only GPS signals. As the GPS signal is not authenticated any broadcasted synthetic signal can distort the OBU making the complete tolling system into an easily vulnerable system to fraud.

After the German initiative to "charge for use" for heavy vehicles, other countries have decided to join this scheme i.e. the Austrian EFCOM and the Swiss Thomas Kallweit of FELA GmbH. The two tolling systems are based on the same principle; GPS based tracking with a communication channel.

A typical tracking device is composed of a GPS module and a communications module such as a GPRS modem or radio modem. Some tracking devices additionally include a microprocessor with software to process the data from the GPS module. There are a number of limitations in current GPS modules:

- There is no cryptographic authentication or integrity protection of NMEA position, time or velocity data sourced from the GPS module
- The NMEA location data from the GPS module can be trivially simulated. In addition to the limitations of GPS modules, the lack of authentication and end-to-end communications security between the tracking device and the telematic server can exacerbate the possible attacks that can be performed, such as masquerading as the tracking device to falsify location.

Thus, there is a crucial need for a new system based on integrity of data, higher positional precision and anti tampering with an authenticated data generation if a pan European tolling system is desired. Additionally, a contractually guaranteed level of service is critical to ensure system functionality. In order to fulfil these basic requirements, at the very least an augmentation system such as EGNOS is needed, to provide GPS signal integrity. Nevertheless, it is not recommended to base a European service solely on a positioning system under the purview of a non-member of the European community. Consequently, the use of Galileo is not only desirable due to the increase in the number of satellites but also to guarantee service in all of the possible situations where foreign systems may not provide suitable signals due to such reasons as government policy, selective availability (S/A), jamming etc.

TOLLING SCHEMES

Analysing the history of tolling, one observes that in the last 15 years, tolling has undergone a complete restructuring. It has evolved from the classical manual toll collection with booths to new systems which allow drivers to move in and out of toll systems without delay. The study performed on [2] for the Texas Department of Transportation presents the Electronic Toll Collection (ETC) as a mature mechanism (in road sensors, overhead cameras and vehicle to roadside communication). They analysed a number of promising upcoming technologies such as odometer tolling, cell phone tolling and satellite tolling, where special attention was paid to this third approach. The study assesses that this kind of tolling is touted to become the preferred method of ETC due to its flexibility and allowance for including time and location variable tolls.

Therefore, it is important that the newly designed road pricing system comprises each of the tolling schemes existing today and should also be flexible enough to add the newly discussed road pricing systems with only minor changes in the platform.

The main types of tolling schemes existing nowadays are described in [3]; nevertheless we herein list important examples to show the diverse nature of each scheme.

Toll plazas usually used in motorways, tunnels and bridges. They are used in closed road networks and cause delays at payment barriers. The technology behind this kind of tolling is the manual charge on specific booth, video tolling and microwave or infrared.

Open road tolling is used in nationwide motorways schemes due to its open, barrier-free architecture allowing high traffic throughput. The technologies behind this kind of tolling are microwave and infrared tags, satellite positioning coupled with GSM, and satellite positioning coupled with Smartcards.

Congestion charging is nowadays used in some cities and urban areas and its main purpose is to reduce city congestion and encourage the use of public transportation. The technologies behind this tolling system are video surveillance, microwave and infrared tags, and satellite positioning coupled with GSM. This kind of tolling has now been set up in cities such as London, Singapore and Melbourne, while it has been up and running for decades in cities in other countries such as Norway

Within these tolling schemes, different categories can be distinguished such as zone-based schemes and road segment based schemes, where each category can be divided into several tolling modes. Within the zone-based schemes the following ones can be distinguished:

Area toll – tolls for driving in a tolled zone, no matter how often vehicles enter within a certain period.

Cordon toll – tolling for vehicles entering or leaving a zone.

Time-based toll – vehicles charged on the basis of time spent within a zone or on a network.

Measured distance toll – toll levied according to the exact distance travelled within a defined area.

The road based schemes can be divided two main categories:

Road segment toll – tolling charged for driving on specific segments of roads such as bridges and tunnels, or the truck tolling scheme in Germany.

Closed network toll – fee depends on where the network was entered and exited.

Nowadays, there is no system gathering all these tolling schemes. Current systems are fixed and offer no flexibility to change the tolling system without an enormous investment. Consequently, future tolling systems must address all these kinds of tolling schemes in a flexible manner and should be prepared to be extended to new areas without significant additional costs. This implies the need to avoid structural elements such as booths which make it impossible to easily switch systems; furthermore, these elements increase the structural costs of the tolling system. Therefore, the best solution would be to use a hybrid system satellite based on satellite positioning and a communication channel.

REQUIREMENTS OF THE SYSTEM

The implementation of such a system involves an on board device including a GNSS receiver and mobile network communication equipment connected to a back office or control centre where the vehicle information is received, processed and the fee is charged. This back office will also be responsible for distributing toll revenues and proportional refunds to the corresponding road authority.

Different mobile communication solutions will be analysed in order to define and implement the most efficient transmission channel (in terms of bandwidth, availability, continuity, cost, privacy and reliability). Current edge technologies such as 3/3.5G (UMTS, HSDPA/HSUPA) should be used as to near future evolutions like HSOPA shall also be considered. Generally, all pertinent technologies under definition in the context of 3GPP LTE (Long Term Evolution) should be studied and considered for the further enhancement of the platform

Figure 1 shows the overall architecture of the system.

On-board Unit: The OBU is composed by different elements

- The combined GPS/Galileo/EGNOS receiver shall improve the nowadays available positional precision, checking data integrity via the EGNOS and Galileo systems. Vehicle position shall be available over 99% of the time to ensure the correct operation.
- Communication modules for transmitting the position and charging characteristics. In addition to the precise position and data integrity monitoring performed on the device, this data will be transmitted to a central control system through a communication module incorporated into the receiver. Nowadays, the typical communication channels for this kind of application are GSM/GPRS. New communications channels that could provide major benefits in terms of bandwidth and latency (to improve response time). These communications networks are: UMTS networks, HSDPA/HSUPA technologies, “Beyond 3G” standards and protocols, and in general, all future emergent standards from organisations such as like OMA and the 3GPP. Data encryption and protection, along with the most efficient radio access method, data encapsulation, format and protocols for transmission will be analysed.
- HW/SW anti-tampering solutions. GNSS and communication On-Board Units (OBU) must be designed to prevent any kind of tampering or manipulation by users/drivers.

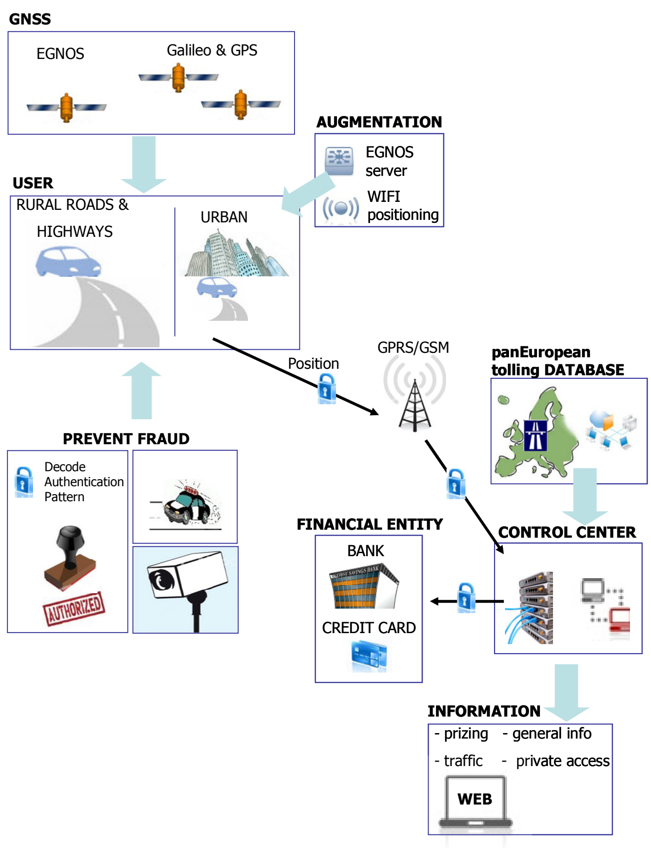

Figure 1: System Architecture

The OBU shall be a reference design that may be manufactured by different companies. The OBUs could have different characteristics and target prices. Every OBU shall be implemented and tested to demonstrate their ubiquitous compatibility. For this purpose a set of well defined interface and communication protocols must be defined. The OBUs to be used in the tolling system shall fulfil the following aspects:

- Meet general requirements in terms of availability, accuracy and integrity;
- meeet communication standards ; and
- certified by an authorised entity

Control Centre or Back Office: is composed by several elements:

- SW authoring tools to facilitate and provide flexibility to include new tolling routes, change tolling schemes on road or urban segment, etc. The system must be designed to be scalable and adaptable for future tolling schemes.
- Database that will support a large number of simultaneous users. One of the most critical components of the system is the database since it must be designed for always-on operation whilst being scalable and extensible through the addition of new services or features.
- Distributed control centre, which means that each region should have their regional control centre for managing the vehicles travelling on their infrastructure. The control centres shall be interoperable and with a standard interface in order to allow communication with most (if not all) of the commercial OBUs.

AUTHENTICATED ROAD PRIZING SYSTEM

Authentication, availability and integrity of the location data will be one of the key issues to address for revenue protection and anti-fraud measures. There have been a number of recent efforts to quantify the extent of vulnerabilities and limitations that the GPS civil signal imposes on civil critical applications such as road pricing. One of the most prominent vulnerabilities of GPS-only based system fraud is the non-authenticated signal provided by GPS. As the GPS civil signal is not authenticated, it can be simulated. In recent years, simulators have become widely available; moreover, a GPS simulator can be rented relatively cheaply and the signal can be used to feed the OBU antenna. Consequently, it is of great importance to analyse the authentication features offered by the Galileo signal to design a robust and secure tolling system.

One of the possibilities that Galileo will offer is *Signal Authentication through Authentication Navigation Messages (ANM):* The ANMs would include a digital signature authenticating the other navigation messages that contain data including ephemeris and almanac data. Using the digital signature, the certified receiver is able to authenticate the source of the messages and verify their integrity.

There are other possible authentication modes such as *Signal Authentication through Spread Spectrum Security Codes (SSSC):* SSSCs are synchronous cipher streams seeded by an unsent digital signature from an Authentication Navigation Message, interleaved with normal spreading sequences; or *Signal Authentication through Spreading Code Encryption (SCE):* Spreading code encryption is one of the oldest signal authentication techniques, currently used by the GPS P(Y) code, an exclusively military service, which will provide authentication of the Galileo CS and PRS signals.

The robust OBU design will include an authentication mechanism as presented in figure 2 and 3:

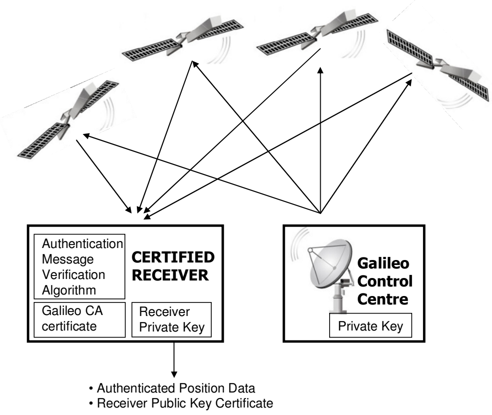

Figure 2: :System Authentication Procedure Scheme

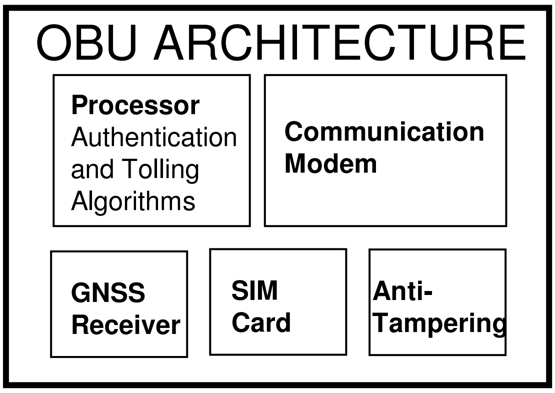

Figure 3: System Authentication Procedure and details on OBU design

DESCRIPTION OF THE SYSTEM'S HIGH LEVEL OPERATION

Analysing the system's high level operation at an early development phase is crucial to guarantee the success of the road pricing platform. The complete system can be divided into four different services that work individually (Figure 4):

User Service: User Services aim to provide the road user with an easy means of settling their Toll account. It has taken into account that this service will interact with a number of charging services and technology providers. Therefore, standards and open interfaces are required

Charging Services: The role of Charging Services is to identify when a road charge is due, calculate (or receive from the OBU the total amount per road/area) the amount and bill the user.

Compliance Enforcement: The role of Compliance Services is to verify that all road users are complying with the rules of the scheme.

Operation and Management: The role of Operation and Management is to define the road pricing and the related scheme ensuring that these are compliant with the system. Additionally, it holds the final responsibility to manage the system as a whole.

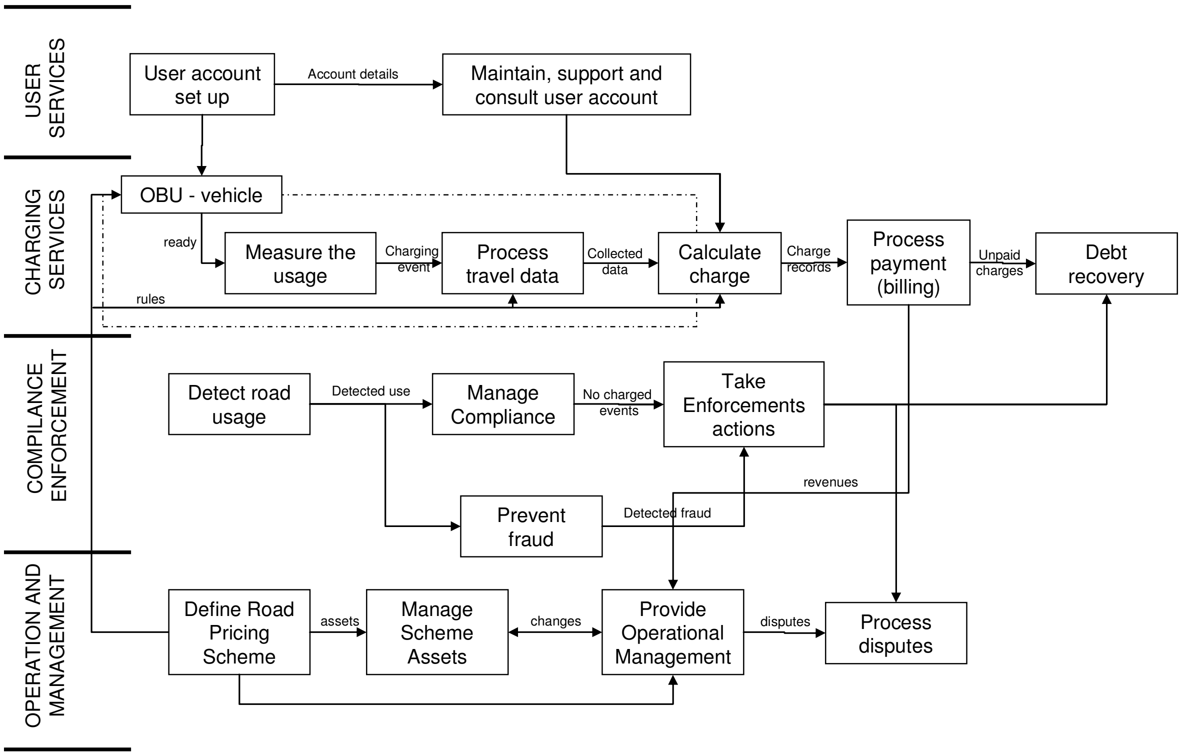

Figure 4: Preliminary System high level operation chart

PRELIMINARY STRUCTURE OF THE SYSTEM

Special emphasis must be given to the design of the most crucial elements of the system, namely the GNSS based localization device and the back office control system.

GNSS Receiver

This receiver shall combine (down convert and process) different frequency bands and signals e.g. GPS/EGNOS/Galileo and GPRS. Therefore, the first critical element is the Frontend design. Low-IF architecture is one of the most promising solutions because of the possibility to integrate most of the required components into a single chip solution. Additionally, Low-IF avoids problems with Flicker noise and DC offsets. Figure 5 shows in a schematic picture of the architectural elements required to develop this kind of Frontends.

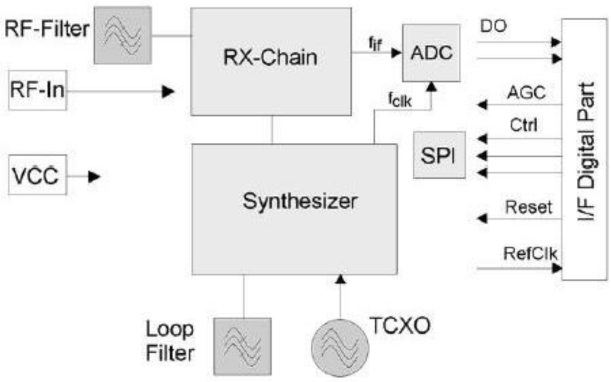

Figure 5: GNSS Frontend architecture

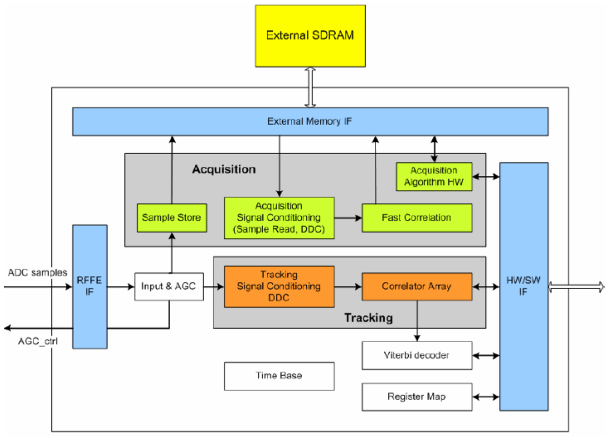

Figure 6: GNSS signal processing scheme

The next step is to design and develop the signal processing unit which will be able to acquire and track the signal from different kind of satellites and positioning systems. Therefore, reconfigurable and system independent modules are needed to handle different signal types in parallel. The most convenient architecture is shown in Figure 6

For acquisition a fast and high sensitive algorithm must be implemented using HW FFT matrix modules. For tracking specially designed correlator modules are use to handle the differently modules signals BPSK, BOC(1,1), and AltBOC. Application Specific DSP on FPGA/ASIC shall be used to maximize the system's capabilities.

Once the GNSS signal is processed, the position must be calculated hybridizing the information coming from the satellites, augmentation systems and assisted data. Therefore a flexible software solution shall be designed.

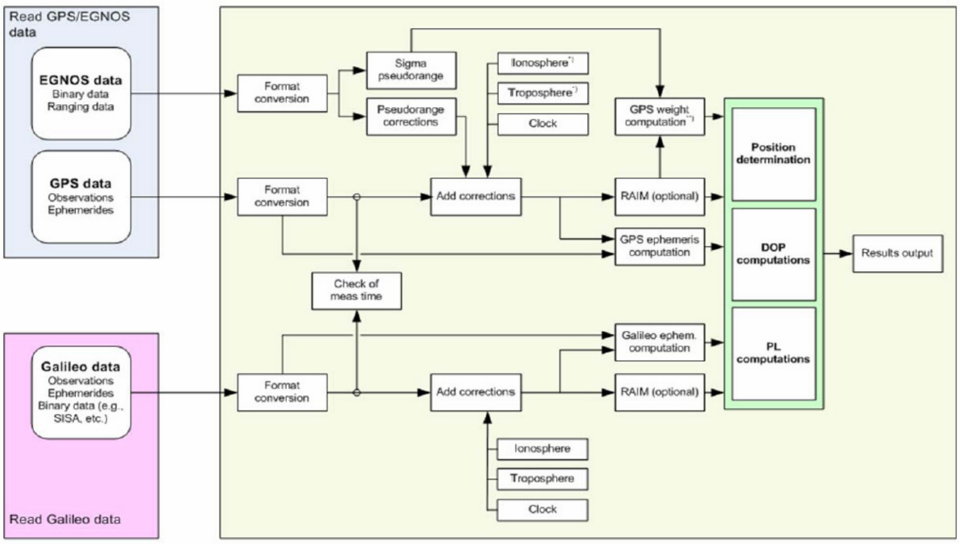

Figure 7: Position calculation software modules

The main challenges to be faced in the design of these modules are:

- Implementation os a modular structure enables integration and replacement of SW modules;
- Processing of the differences between Galileo and GPS system time and UTC ;
- Routing of acquisition aiding data; and
- Computation of quality and integrity data based on the specifications of [DO229B]. Thus, the receiver can be used even for demanding safety and security applications.

Control Centre

The back office or control centre network design is of great importance for the development of a pan European tolling system. It should be noted complete flexibility in the location of back offices must be considered since each region shall be able to manage its own road system. The system will have a distributed architecture where each back office shall control vehicles within a given range and provide them with tolling fares and models. Switching between control centres can be achieved through a mechanism analogous to mobile phone roaming, as the communication module is able to detect when the user enters/leaves a region/cell (handover). An automatic switching application will be implemented to contact the most appropriate control centre. Additionally, this cell-based positioning system will be used as an enforcement tool to validate the user's position irrevocably as a redundant system.

This distributed solution presented in Figure 8 has the following benefits:

- Total flexibility
- Robustness against single failure of a complete control centre. In this case, the action range of the adjacent back offices will be enlarged to cover the zone;
- Ease extensibility to new areas
- More efficient tolling as each control centre has only minimum information about tolling for other regions; and
- Better response and up-to-date data maintenance.

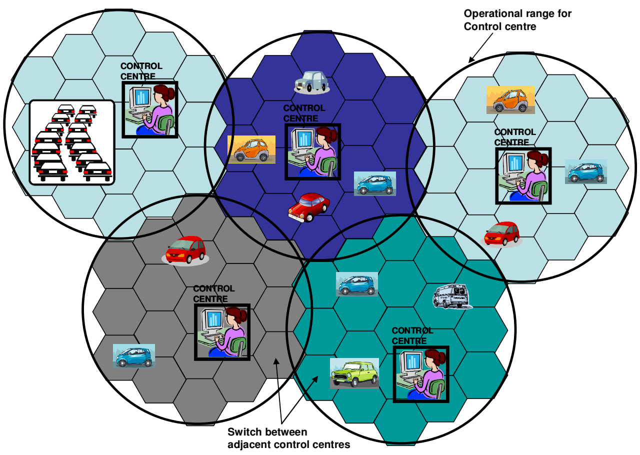

Figure 8: Distributed Control Centre scheme

Control centre switching will be performed through calculation of the vehicle's position (OBU) and will be coordinated directly in the vehicle not to overload the control centres.

The position of the vehicle is calculated using GPS/Galileo satellites and EGNOS signal in either of its two modes: SIS and terrestrial link. For terrestrial link implementation, SISNeT (Signal in Space through the Internet) technology shall be evaluated to guarantee data integrity. Through SISNeT, irrespective of the GEO visibility conditions, any user with access to the Internet (usually through wireless networks - GSM or GPRS) can access EGNOS data.

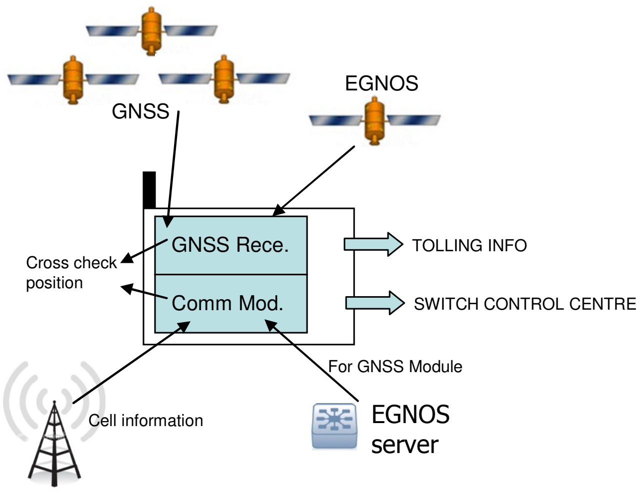

Figure 9: Position and communication cell calculation

It will also be possible to roughly calculate an approximate position of the user using the communication cells through the communication channel. The accuracy of these mobile network-based positioning technologies is not high, and typically depends on the scenario and environment. Accuracy is much lower in rural areas; whereas in dense urban areas the number of base stations is much higher and thus the size of the cell is smaller, enabling a more accurate estimation of the position). Apart from this elemental Cell-ID mechanism, other improvements or variations (such as Enhanced Cell-ID, Timing Advance, E-OTD, TOA, etc) could be used if the conditions make it possible (number of visible base stations, receiver capabilities, network design, etc.). In any case, it is likely that this position calculation is not sufficient for tolling purposes, but it can be use as redundant enforcement for billing.

Nevertheless, this cell position is of great importance when switching between control centres. Through a cell-based area partition, the OBU will be able to decide which one is the best control centre to contact. Figure 10 represents how the switching is performed. Between contiguous cells, a transition zone is defined where the car is still sending the position data to current (serving) control centre, but is also contacting the next ("visiting", using mobile network nomenclature) back-office.

To find out which one is the most appropriate control centre to couple with, a geo-located list of the control centres will be sent periodically, keeping this information up to date in every vehicle's OBU.

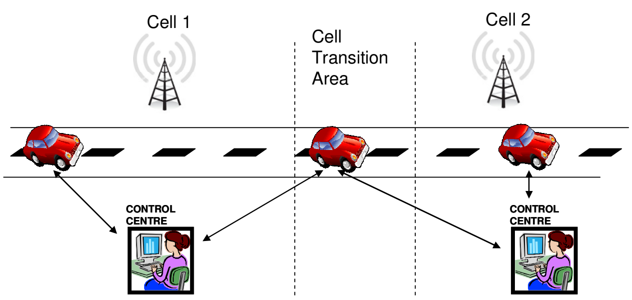

Figure 10: Switching between Control Centres

OTHER APPLICATIONS

Vehicles equipped with OBUs will be able to extend the applications for on board devices. The OBU of the vehicles contains the precise position of the vehicle continously allowing further innovative application that can be derived from this technology.

Pay per Use vehicle insurance

Market analysis of satellite-based applications for road users suggests that pay-per-use insurance should become normal practice in future. Benefits claimed for pay-per-use insurance include more personalised premiums, promotion of good driving habits and a reduction in road accident casualties.
Galileo will enable the accurate positioning information needed to support differential premiums depending on where a vehicle is used.
Pay-As-You-Drive ("PAYD") insurance means that your insurance payments are based on how much you drive. The Victoria Transport Policy Institute [8] says that PAYD insurance will "help achieve several public policy goals including fairness, affordability, road safety, consumer savings and choice, and reduced traffic problems." Fairness will be improved because the user's financial costs will more closely match their accident risk--to say nothing of their burden on the roads, traffic, and the environment.

Traffic Management

This technology offers a unique opportunity to track significant behavioural patterns of each vehicle. Vehicles in the system will act as collateral fleet of “floating cars”; therefore, this system enables not only charging for the selected road infrastructure but also allows active traffic management. It, therefore, significantly contributes to the increase of traffic safety as well as to environment protection.

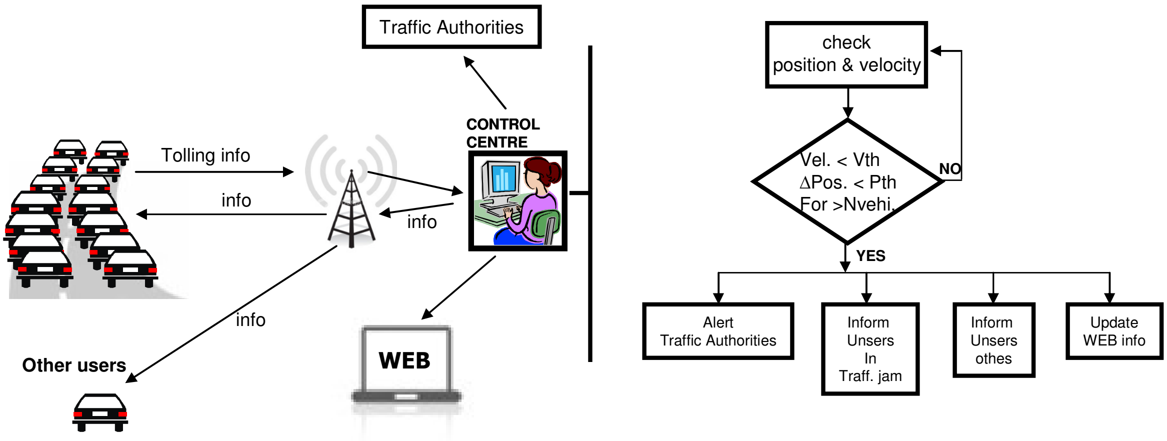

Figure 11: Traffic Management application

Figure 11 shows one of the possible related services for managing traffic and congestion. In the case of congestion management, the system will be able to react dynamically activating the alarm protocol and the information chain for users driving in this direction. The control centre in this case could temporarily adjust the toll price for this route and communicate the change to the relevant vehicles in an attempt to discourage them from using the route and adding to the congestion.

CONCLUSIONS

This work presents a discussion on a new Ellectronic Tolling Systems. Some innovative methods to raise revenues for road agencies or charging congestion, recently adopted or being planned for adoption by several countries has been analysed.
It has been shown that GNSS based systems for road user-charging are feasible, since location and time is continuously available anywhere. Additionally, GNSS based systems offer high geographic charging flexibility.
The required robustness, availability and affordability of GNSS based systems will improve over time because of Galileo.
Finally, this study aims at exploiting the capabilities offered by EGNOS and Galileo to provide such new applications; specifically, an extended service concept of road tolling is addressed in the present paper, but also additional pay per use services on motorways as well as in urban environments (parking and access to restricted zones) are described.
Independent on the environment considered in the service scenario, common services applicable to each category of users are also considered, including the distribution of real time traffic data. Other interesting services are also presented such as pay per use insurance that can be easily implemented by the same satellite based tolling system. Nowadays it is noted that the user community sees with good eyes this kind of innovative actions which will help to have a more adequate inssurance.

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