GINA -GNSS FOR INNOVATIVE ROAD APPLICATIONS-: EGNOS / GALILEO FOR ROAD USER CHARGING AND VALUE ADDED SERVICES

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Abstract *Galileo / EGNOS can be key to reduce the negative impact of road transport and offer new business opportunities, such as road pricing and other Value Added Services. The GSA/EC co-funded FP7 project GINA addresses the adoption of EGNOS/Galileo in the road sector considering technical feasibility on a large scale, economic viability and positive impacts in aspects such as congestion and pollution. The project leverages on three main activities: analysis of the context for a nationwide GNSS-based road pricing (and VAS) solution giving emphasis to business aspects- , implementation of a nation-wide large-scale demonstrator of GNSS-based road pricing (having the ABvM system promoted by the Dutch Government as a reference) and VAS (complying with requirements defined by real end-users) and a solid dissemination strategy. This article addresses the added-value of position integrity in these applications and the setting up of a large scale demonstrator in the Netherlands using EGNOS, detailing aspects of the trials such as objectives, equipment and infrastructure involved or context description.*

1. INTRODUCTION

Passenger car fleet is growing in all Europe and this growth becomes especially critical in highly populated areas as big cities and surrounding regions. The use of Personal Navigation Devices (PND) is booming, and this increase is creating a platform for applications beyond navigation. The situation faces major challenges such as the increase of safety on roads, funding of road infrastructure and reduction of congestion and pollution.

Different schemes are being proposed to

improve the situation, amongst them, road pricing. Other applications with high potential are Pay-as-you-drive (PAYD) schemes for the insurance sector, leasing companies etc. and other Value Added Services (VAS) such as local mobility information and others, which may fund part of the cost of a road pricing system and can take the benefit of the equipment and infrastructure developed for this system.

There are still several obstacles to a large scale take off of these services. The GINA project intends to address these obstacles and bring road pricing and road VAS a step closer to maturity. GINA will be addressing the adoption of EGNOS and Galileo in the road sector considering the technical feasibility of the concept on a large scale, its economic viability and positive impacts in aspects such as congestion and pollution as a general scope.

This article will describe the main objectives of the GINA project and how it will go a step beyond the current situation with respect to the use of European GNSS in road applications (mainly Road Pricing and other Value Added Services). Later, the trials which will be carried out in the context of the project will be described in detail. The article will concentrate on remarking those features - such as positioning integrity - which can foster the widespread adoption of European GNSS as a reference technology for the implementation of road applications.

2. THE GINA PROJECT APPROACH AND INNOVATION

A. The project context

GINA is a project co-funded by the GSA / EC under 7th Framework Programme for Research and Development which is addressing the adoption of EGNOS (and Galileo, in the future) in the road sector, considering the technical feasibility of the concept on a large scale, its economic viability and positive impacts in aspects such as congestion and pollution, as a general scope.

The project pursues these objectives leveraging on four elements:

1. The analysis of the context (legal, regulatory, interoperability, standardization) affecting a nationwide GNSS-based road pricing solution (and VAS running on same platforms)

2. A thorough market and business potential analysis for the applications (road pricing and VAS) to base a commercially feasible large scale adoption of the solution.

3. The implementation of a large-scale demonstrator of GNSS-based Road Pricing at national level and VAS (PAYD for car leasing companies and traffic information generation, modeling and provision). The demonstrator will be fully based on the planned ABvM system being defined by the Dutch Government (as far as information is available and public) (being the Netherlands the first and unique nation deploying a nationwide road pricing scheme based on GNSS only)

4. A solid dissemination strategy which contributes to the GNSS adoption for road pricing and VAS and makes awareness of the benefits of the use of EGNOS and Galileo to the different stakeholders.

GINA will be bringing a realistic use of EGNOS and road pricing/VAS applications together: the OBUs used in the trials are the only ones using EGNOS and providing positions with integrity which have been tested in real trials (TfL CLoCCS, ABvM in the Netherlands) and real applications will be demonstrated, satisfying the requirements of real end users (such as the Dutch Government for road pricing or real commercial users -a car leasing company, ARVAL- for Value Added Services).

In addition, the GINA project solution will be close to the commercialization of the product / system proposed as a clear market approach is leading the work from the beginning of the project, exploiting the concept of the use of the same onboard unit (and infrastructure) for multiple purposes and services.

The solution proposed by the project is subject to be adopted and replicated in other countries and by different users due to the fact that it contemplates the current regulatory and standardization framework, it is based on the use of GNSS-only technology with no need of specific roadside infrastructure and thus highly versatile and it is conceived to be interoperable and easily replicated in other contexts.

This article will detail the way GNSS is applied in this context and the implications of position integrity for road user charging. In addition, the way the proposed large scale demonstrator will be tackled is described.

B. The use of integrity in road pricing

GNSS-based road user charging allows for flexibility and scale not previously possible in a cost efficient manner. Such systems are however new, complicated, expensive, and can be arranged in a number of ways some of which may not yet be known. In addition, the combination of GNSS based charging and human users creates at least two major challenges:

● First, satellite positioning was originally developed for situations in which the user would be assisted by the technology, and hence has an incentive to make conditions ideal for technology performance. In contrast, a system deployed as part of a tax or charging scheme, is less likely to be treated as friendly by its users.

● Second, there are inherent weaknesses in satellite positioning. In other types of applications, such as navigation, this weakness can often be mitigated with intuitive human information processing. With an automated system, as is necessary for electronic tolling, it is not practical to know when to ignore the system and when to trust it. This also carries legal implications.

Indeed, while having very good average performance, GPS is affected by some factors which have an impact in the resulting errors associated to it:

● NLOS Multipath: in urban and semi-urban environments multipath provokes large errors (› 100 m with a probability ›0.1%)
·
● Interferences (deliberate or non-deliberate) / Spoofing
·
● Ionosphere-related
·
● Satellite failures (15 satellite failures per year in average with associated errors of more than 100 m at some European locations on some occasions)

In order to compensate for large position errors, a GNSS-based road user charging system might opt for the introduction of additional sensors (to the OnBoard Unit) and / or roadside infrastructure, which involves a complex and non cost-effective solution.

Alternatively, the use of position integrity is proposed.

For a Road Pricing system as the one targeted in this proposal, GNSS is used for two main processes:

1. First, in support to distance measurement either in isolation or in combination with other sensors such as odometers.
2. Second, for the identification of the so called GEO objects, i.e. the areas in which charging (or special tariffs) are applied.

For the particular case of the Netherlands, the concept of GEO objects appears twice:

● One, for the definition of The Netherlands borders, considering that charging applies for the vehicles circulating within the country

● Second for the identification of areas or road segments in which special tariff applies during certain periods of the day. As a matter of fact two types of zones are identified in this category: urban areas (such as Amsterdam) and specific road segments each one identifying a different type of GEO object, so called cordon and segment respectively.

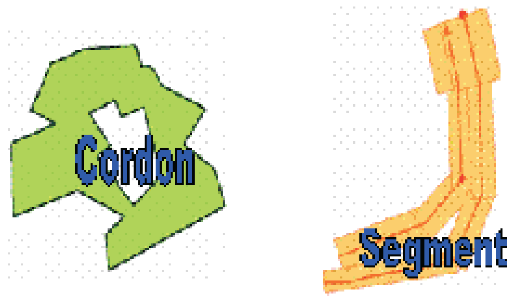

Figure 1. - Examples of GEO objects applied in the ABvM

GNSS integrity is used in the two main processes described above. On the one hand, position and velocity integrity helps in the distance measurement process by increasing the reliability of the computation and guaranteeing that distance will not be measured in excess. Two approaches are possible (and both will be tested along the trials) including the use of GNSS only information and, as an alternative, the calibration, using that GNSS information of the measurements provided by the odometer.

Second, and more important, position integrity is used in the process of GEO objects identification. The way integrity is used to guarantee that the vehicle is in the zone and thus avoiding the overcharging of a vehicle that did not enter that zone is a key technology developed by GMV that is briefly described below and is a major asset for the road pricing trials as well as the best reference to exploit the use of EGNOS and Galileo integrity.

The use of integrity in road pricing has two main steps: first the computation of position integrity and second its use in a reliable charging algorithm. Both are briefly defined next.

Computation of position integrity: The on-board receiver is specially designed to compute, in addition to classical position, velocity and time (PVT) the so called Protection Levels (concept introduced by the civil aviation). The Protection Level defines a circle around the estimated position in which the actual position is guaranteed to be with an extremely high probability.

This protection level is computed thanks to the integrity information of EGNOS but also by

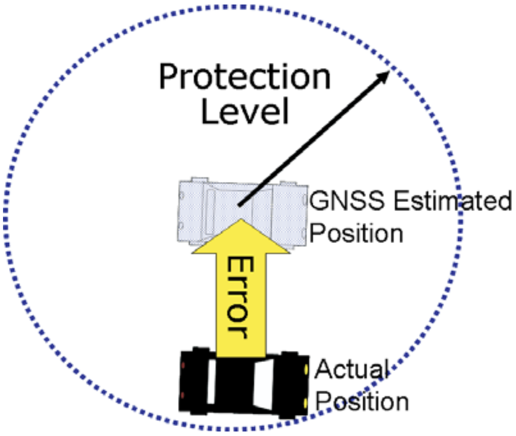

Figure 2. - The concept of Protection Level

specific algorithms that account for local errors such as non-line-of-sight multipath.

Translation of position integrity to reliable charging: In the simplest implementation (other more complex technology is defined and will be tested in the trials), the charging algorithm decides that the vehicle is within the GEO object only when the Protection Level centred in the computed position is completely within the corresponding GEO object, e.g. a road segment. Thus probability to have a wrong decision is extremely small (as small as the integrity risk associated to the protection level computation).

The following figure shows an example of a vehicle running in a free road parallel to a toll highway. A temporary large error in positioning has implied that the car estimated position is on the toll highway. This would be translated in an incorrect charging if using a normal (without integrity) GPS receiver. When integrity is used, the large position error would also be associated to a large Protection Level that would indicate to the system that there is no certainty that the vehicle has used the tolling

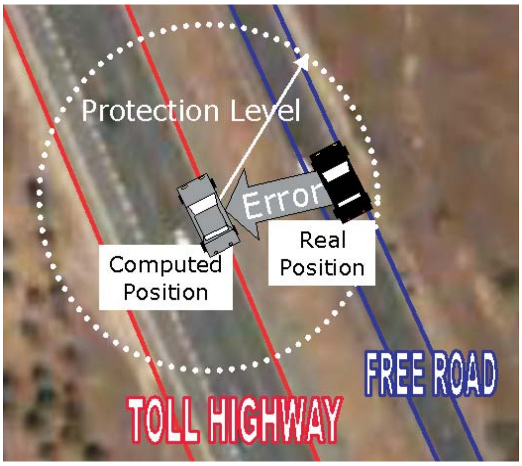

Figure 3. - How Position Integrity avoids overcharging

infrastructure and, therefore it would not be charged (in dubio pro reo approach).

It could be well argued that other circumstances (e.g. car driving in the tolling highway with an error indicating that the vehicle is in the free road) could not be compensated with the use of Protection Level, what is totally true. However, it is essential to understand that the requirement not to overcharge (1x10-6) is much more demanding than the one associated to the charging probability that is in the order of magnitude of 99.9% and then it is essential that the technology pays special attention to the overcharging problem. As it has been stated by many experts if a charging system charges incorrectly a non user (or a telephone operator charges a user for having called a number he did not dial) and the associated probability is not extremely small, the system will loose credibility and will finally fail.

C. The GINA project trials

The GINA project will be implementing a large scale demonstrator at national scale (in the Netherlands) for Road Pricing and VAS (PAYD for car leasing companies and traffic information generation, modelling and provision). The overall objective of the trials is to demonstrate how, and especially, with what performance, GNSS technology based on the European GNSS infrastructure can support the implementation of a Road Charging scheme as the one identified in the Netherlands as well as to justify the added value of this technology as compared to GPS-only in terms of performance or cost improvement.

Two different trial levels are addressed:

1. Exhaustive performance analysis trials, where particular conclusions regarding the performance of EGNOS/Galileo (as compared with very accurate references) in terms of GNSS performance, distance measurement, GEO objects identification, charging performance, versus other systems (such as GPS or alternative technologies) will be obtained. Special attention will be devoted to the end-to-end charging performances in comparison with the existing requirements of the ABvM system (mainly charging accuracy and overcharging probability), as far as this information is available.

2. An end-to-end performance analysis, where an overall assessment of the capabilities of the system from different perspectives and an exhaustive one for variables where a reference system is not needed.

Type	No. car	Time	Driver	VAS	Ref. System needed	CAN BUS	Eva-luation	Route
End to end	100	6 month	ARVAL clients	Yes	No	No	Appli-cation level	Free, not fixed
Exhau stive	2-3	4 week	Project control	No	Yes	Yes	GNSS Perfor-mance	Fixed by project

Table 1. - Characteristics of GINA Project Trials

Both trial levels are very different in nature and the approach to be followed in each level is summarized in the following table:
Both types of trials will allow analyzing different interesting aspects which will help to get

conclusions with respect to the use of European GNSS for road user charging.

Starting from the key system elements and actors involved in a generic GNSS road user charging / VAS system and the main exchanges of data & information between them, some platforms already existing have been properly customized in order to implement the elements of the architecture necessary for the project trials / demonstration.

The proposed architecture was defined to verify the feasibility of the requirements of current and future standards and regulation for EFC, such as ISO/TS 17575, the EFC Directive (2004/52/CE), ABvM. It also demonstrates how multiple services can be supported with only one platform (RUC, VAS PAYD, traffic information generation, modelling and provision are envisaged to be supported by the platform) to mitigate the system development and deployment costs. These requirements led to a modular approach, allowing the isolation of the different platforms and simplifying the introduction of new elements in the architecture.

The interfaces among the elements were defined as web services to provide an interoperable solution, where each Service provider can communicate transparently with a different service provider (e.g. of another Member State), as long as the proposed interface stays the same.

Also, in order to comply with the strict privacy requirements of the ABvM, a Smart OBE approach was chosen over a thin client architecture. Since no positioning data can be transmitted linked to a user's identity, it is the OBE which handles all the geo-object calculations. In those Member States where the regulation is less strict, more complex Value-Added Services can be developed on the advanced OBE, increasing the perceived value of the system by the end-users.

The following figure displays the architecture of the GINA demonstrator with the interfaces and

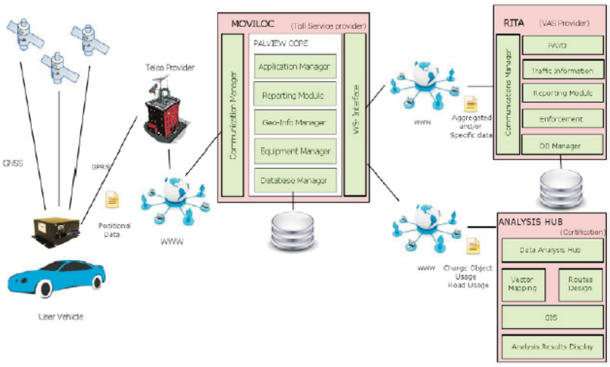

Figure 4. – GINA Demonstrator architecture

communication channels among the involved platforms and the main modules composing each of them:

The exhaustive performance analysis trials aim at getting particular conclusions regarding the performance of EGNOS/Galileo (as compared with very accurate references) in terms of GNSS performance, distance measurement, GEO objects identification, charging performance, versus other systems (such as GPS or alternative technologies). Special attention will be devoted to the end-to-end charging performances in comparison with the existing requirements of the ABvM system (mainly charging accuracy and overcharging probability).

The objectives of this trial level set out that the following should be measured:

1. GNSS performance:

   a. GNSS Accuracy (i.e. positional accuracy)
   b. GNSS Integrity in terms of integrity risk (statistics of position errors with respect to PL sizes; Standford diagrams or similar)
   c. GNSS Integrity in terms of size and availability of protection levels

2. Distance measurement performance (accuracy of distance measurement)

3. Performance of GEO-Object Identification:

   a. Implications to distance

measurement within geo-objects

b. Wrong and missed identification of geo-objects

4. Charging performance

a. Overall distance measurement accuracy per zone

b. Overall charging measurement accuracy

c. Charging Availability (according to GMAR proposal)

d. Charging Integrity (according to GMAR proposal[1])

In order to measure the above, accurate reference data will be used for position and driven distance. Both position and driven distance measurements will be assessed with four different configurations used in the reference vehicle:

- GNSS only OBU performance
- GNSS + EGNOS OBU performance
- GNSS + CAN Odometer OBU performance
- GNSS + EGNOS + CAN Odometer OBU performance

The measurement of driven distance has a defined accuracy requirement, derived from the target accuracy of the proposed Dutch KMP system which states that 99% of bills should have an error of less than 1%. As the bills are derived directly from driven distance (although recognizing that the requirement for differential pricing means this is not a direct mapping), this implies that the mechanism for deriving driven distance should be accurate to within 1%.

There are a number of ways of undertaking this measurement and the strengths and weaknesses of some approaches should be considered. Direct measurement of cumulative driven distance by reference equipment installed in the vehicle, normally on a second-by-second basis will be measured. This can be done in a number of ways, but to achieve accuracy and reliability of measurement must include an odometer input from the vehicle, preferably automatically and continually calibrated by on-board high-accuracy differential GNSS equipment. The driven distance recorded by the OBU under test is measured against this reference distance. Comprehensive analysis of partial journeys, distance within geo-objects etc is also possible.

This solution provides reference distances for all driven distance, including unmapped roads and is not dependent on the accuracy of underlying information (e.g. maps). It also allows the arbitrary placement of geo-objects.

The end-to-end performance analysis covers two main objectives:

1. An overall assessment of the capabilities of the system from different perspectives including the analysis of the capability of the system to generate invoices according to the requirements of the ABvM system, evaluation of the drivers reaction and feedback, study of the capabilities of providing added value services including both technical data and also assessment of users, feasibility of a simple enforcement mechanism, effect of interferences in the system performance etc.

2. An exhaustive performance analysis for those variables where a reference system is not needed including an estimation of the overcharging performance, evaluation of performance under different RUC schemes (time-based, cordon etc.), capability of getting repeatable results for the same conditions etc.

1 The GNSS Metering Association for Road User Charging (GMAR) was established to create the GMAR Performance Analysis Framework (GPAF) to quantifiably address performance issues related to road-use metering. Experts from Britain, Canada, Belgium, France, Germany, Netherlands, Spain, and Sweden have drafted a body of criteria, characterizations, tests and analyses specific to Charging Reliability. The measurement criteria are related only to charging data as opposed to distance or other accuracy metrics. Hence, GPAF analysis is independent of on-board technology, algorithms, processing or interconnection to vehicular systems.

For all of these objectives, sufficient data will be captured to make any results statistically significant. The end-to-end trials will collect varying (but potentially extensive) data on known GEO-Objects operating within known (defined) areas. The OBUs will be configured to recognize all GEO-Objects set up and to log specific times of entry/exit and distance travelled within the Object. Although other parameters such as journey start and end times and total distances travelled are not directly useful to the analysis, they may be useful for other aspects of the project. The outcome should be a very precise measure of distance accuracy and if tenable an associated measure of integrity for some GEO-Objects.

A very important outcome of this trials level (end-to-end performance trials) will be the feedback collected from volunteers participating in it. The reaction of drivers will be assessed by providing them the data and asking about their reactions in particular to what extent they would be ready to change habits. This will consider potential limitations derived from the privacy law in The Netherlands.

The drivers have been selected from the group of customers of ARVAL NL (a leasing company), taking different data into account, which have helped in the definition of a representative sample (gender, age, profession/reason for driving, driving region during testing, average number of people in the vehicle per journey (it may impact driver's behaviour), time of travel (day or week and time of day). These elements could affect the drivers' feedback.

Another important objective of the end-to-end performance trials is to show the capabilities of providing added value services including both technical data and also assessment of users. To this end, the VAS implemented are those defined by the end-users involved in the project (ARVAL and AENOR), taking account of the constraints imposed by the Dutch Privacy law. In this sense, the services trialled involve Pay-As-You-Drive schemes and generation of traffic information where no access to the volunteers PVT information is possible. At the end of the trials, the impressions of the users with respect to Value Added Services provided will be assessed, concerning aspects such as usefulness of services, ease of use or suggested improvements.

The trials will start on March 2010 and will have a duration of 6 months, after which very valuable information will be available, allowing to build a credible commercial exploitation plan of the trialled GINA system.

The trials campaign will lead to very valuable conclusions and will shed light on the implications of the use of integrity of position in Road User Charging and the use of EGNOS and Galileo in the future for this type of applications.

3. THE IMPACT OF ROAD PRICING IN POLLUTION AND CONGESTION MANAGEMENT

The GINA project kicks off while the European Institutions are still immersed in the debate on the Eurovignette Directive, which lays down common rules on pricing of transport infrastructure, motivated by the greening of surface transport and the need to internalise external costs (allowing for a stable infrastructure financing mechanism) such as those associated to pollution, noise and traffic congestion.

CO2 emissions from cars do not only depend on the car model driven by somebody but they are highly dependent on the driving behaviour used.

The data collected during the GINA project trials will be processed for different purposes and the information obtained will allow analyzing the impact of driving behaviour in pollution and congestion. For this purpose, the measurements of GNSS position and the connection to the vehicles CANbus (allowing to get information regarding fuel consumption,

CO_2 emissions route choice), in addition to the feedback from the drivers, will allow to relate driving behaviour (conditioned by RUC and PAYD schemes) with congestion and pollution reduction and knowing how green the driving during the trials has been.

4. CONCLUSION

This article has presented the GINA project and the way it tackles the adoption of EGNOS (and Galileo in the future) in the road sector, from different perspectives including the technical, the economical and additional elements. The project addresses this challenge implementing a large scale nationwide demonstrator for Road Charging and Value Added Services using the requirements of real end users (the Dutch Government and a car leasing company, ARVAL), complemented by a thorough context analysis (with particular emphasis on business aspects) and an intensive dissemination strategy.

The project revolves around the idea of position integrity, which is used as a road user protection mechanism to prevent overcharging. The position integrity allows guaranteeing the position error limits with a very high probability so that it is possible to charge the drivers using their positions (with integrity) as a basis.

GINA will carry out a complete set of trials which will allow to get specific conclusions with respect to the added value of position integrity for Road User Charging and Value Added Services, concerning the performance of the OBUs to be used with respect to very accurate references for the application defined and concerning the overall performance of the application from an end-to-end perspective.

GINA will also allow getting some conclusions in relation with the energy efficiency of the driving carried out by the participants in the proposed demonstration.

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