



HAL
open science

”EGNOS-ON-THE-ROAD”: WHAT CAN BE EXPECTED FROM EGNOS COMPARED TO GPS FOR ROAD TRAFFIC MANAGEMENT SERVICES

François Peyret, Willy Vigneau, David Bétaille

► **To cite this version:**

François Peyret, Willy Vigneau, David Bétaille. ”EGNOS-ON-THE-ROAD”: WHAT CAN BE EXPECTED FROM EGNOS COMPARED TO GPS FOR ROAD TRAFFIC MANAGEMENT SERVICES. 17th ITS World Congress, ITS, Oct 2010, Busan (Corée), South Korea. hal-04490867

HAL Id: hal-04490867

<https://hal.science/hal-04490867>

Submitted on 5 Mar 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

“EGNOS-ON-THE-ROAD”: WHAT CAN BE EXPECTED FROM EGNOS COMPARED TO GPS FOR ROAD TRAFFIC MANAGEMENT SERVICES

François Peyret

Senior Researcher, Laboratoire Central des Ponts et Chaussées
BP 4129 – 44341 – Bouguenais Cedex - France
+33 2 40 84 59 40, francois.peyret@lcpc.fr

Willy Vigneau

Technical Director, M3 Systems
26 rue du Soleil Levant – 31410 – Lavernose - France
+33 5 62 23 10 82, vigneau@m3systems.net

David Bétaille

Junior Researcher, Laboratoire Central des Ponts et Chaussées
BP 4129 – 44341 – Bouguenais Cedex - France
+33 2 40 84 59 40, david.betaille@lcpc.fr

ABSTRACT

Global Navigation Satellite Systems (GNSS), such as GPS, are more and more playing a key role in the development of new traffic applications and services, such as those making use of “Geofencing” techniques, electronic tolling systems being the most famous among them. Geofencing needs geopositioning and, in most of the case, geopositioning with a certain level of quality, in particular in terms of integrity for the liability-critical applications. The EGNOS system is the European Wide Area Augmentation System for GPS and has been built, upon air transport specifications, to increase the accuracy, but mainly the integrity of GPS system. The French Ministry in charge of Transport, the MEEDDM, has funded a specific study, called “EGNOS-On-The-Road”, to assess, thanks to full-scale experiments in real-life conditions, the improvements that can be expected from EGNOS for road applications, compared to GPS. The authors first describe the experimental test bench, the GNSS sensors and the data processing that have been used. Then they present the results, in terms of availability, accuracy, integrity and in terms of adequacy to the application needs, for several types of sensors: stand-alone GPS receivers or EGNOS/GPS receivers, used with internal and external antennas. The paper ends with a conclusion and high-level recommendations.

OBJECTIVES OF THE STUDY

The “EGNOS-On-The-Road” study has been carried out in 2009, funded by the French Ministry in charge of Transport, to assess in real conditions the performances of GNSS

systems for road transport services. It has been executed by the LCPC, the French public research institute in the domain of civil engineering, and the SME M3 Systems from Toulouse, specialized in the domain of GNSS positioning integrity.

BRIEF INTRODUCTION TO EGNOS

The European Geostationary Navigation Overlay Service (EGNOS) is Europe's first venture into satellite navigation. It was developed by the European Space Agency (ESA) under a tripartite agreement between the European Commission (EC), the European Organisation for the Safety of Air Navigation (Eurocontrol) and ESA (1). In April 2009, the ownership of the EGNOS assets have been transferred from the European Space Agency to the European Commission which now manages and finances the entry of EGNOS into the Service Provision phase. EGNOS has been declared operational for non-Safety of Life applications (Open Service) in October 2009, and its operator (ESSP) has been certified to provide Safety of Life services in July 2010.

EGNOS is the European Satellite-Based Augmentation System (SBAS) that complements the GPS system. It disseminates, on the GPS L1 frequency, integrity signals in real-time, providing information on the health of the GPS constellation. In addition, correction data improves the accuracy of the current GPS services. The EGNOS Service Area includes all European states and has the system-inherent capability to be extended to other regions within the coverage of three geostationary satellites being used to transmit the EGNOS signal.



Figure 1. Overview of the EGNOS system

The EGNOS signal is transmitted by three geostationary satellites: two Inmarsat-3 satellites, one over the eastern part of the Atlantic, the other over the Indian Ocean, and the ESA Artemis satellite above Africa (2). Unlike the GPS satellites, these three do not have signal generators on board. A transponder transmits signals up-linked to the satellites from the ground, where all the signal processing takes place. The sophisticated ground segment consists of 34 *Ranging and Integrity Monitoring Stations* (RIMS), four *Master Control Centres* (MCC) and six up-link stations called *Navigation Land Earth Stations* (NLES).

The RIMS measure the positions of each EGNOS satellite and compare accurate measurements of the positions of each GPS satellite with measurements obtained from the satellites’ signals. The RIMS then send this data to the MCC, via a purpose built communications network.

The MCC determine the accuracy of GPS and GLONASS signals received at each station and determine position inaccuracies due to disturbances in the ionosphere. All the deviation data is then incorporated into a signal and sent via the secure communications link to the up-link stations, which are widely spread across Europe. The NLES send the signal to the three EGNOS satellites, which then transmit it for reception by GPS users with an EGNOS enabled receiver. Considerable redundancy is built into EGNOS so that the service can be guaranteed at practically all times. At any one time, only one MCC will be ‘the master’, with another on stand-by to take over instantaneously should the first one fail. There is redundancy in the up-link stations, too. Only three are needed to operate EGNOS, one for each satellite. The other three are in reserve in case of failure.

TARGETED ROAD TRAFFIC MANAGEMENT SERVICES

The following table presents the main road applications considered in the study, and for which the user needs have been gathered and considered:

SERVICE	MAIN FONCTION
GNSS odometer	Distance measurements at low speed along a road
Truck parking	Static vehicle position monitoring on a parking lot
Geolocated events recorder	Real-time geo-tagging of a road event on board of a patrol vehicle
Hazardous goods monitoring	Monitoring of hazardous goods transport trucks and alarm management when it arrives at the vicinity of a critical place
Geofencing/Electronic Fee Collection	Automatic detection of a vehicle passing under a virtual gantry for road tolling
Geofencing/Corridor	Monitoring of a vehicle supposed to follow a given route
Geofencing/Urban zone	Automatic detection of a vehicle inside a given area in a city

Table 1. Targeted road traffic management services

Among these various services, the two first ones differ from the others given the specific data processing required, the first one needing an integration along the described path to access to the travelled distance and the second one allowing also an integration, this time with the time, since it is a static application in which the accumulation of data can be used to improve the accuracy. The other 5 services can be grouped in a unique cluster we can call “Geofencing applications”. For this kind of applications, the need can be in real-time or not, we considered

that the real-time need had to be fulfilled.

We considered that the main requirements in terms of accuracy only (availability and integrity will also be considered further) were the following:

- Distance error $< 1\%$ of the travelled distance, for the odometer application,
- Error on the mean position < 1.9 m and $R95 < 1$ m, after 30 mn of measurement integration,
- $R95 < 3$ m for all the Geofencing applications.

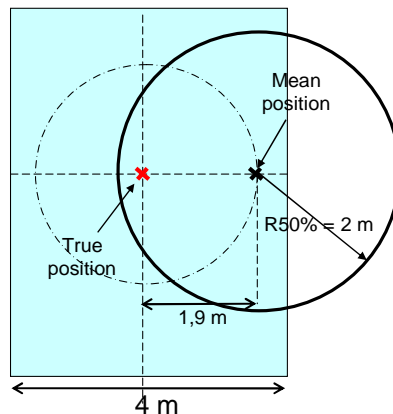


Figure 2. Criteria for the truck parking application

DESCRIPTION OF THE TEST BENCH

For the studies, the LCPC has equipped its test vehicle (Renault Clio Estate) with 3 different L1 GNSS receivers, of low, medium and high cost, and 3 different types of antennas: 1 low-cost patch antenna inside the cabin, the same one on the roof of the car and 1 high cost one, also installed on the roof. In addition, 1 fiber-optic yaw rate gyroscope and 1 MEMS INS have also logged data during the test, together with wheel encoders for further data fusion between GNSS and dead-reckoning. EGNOS messages used for the differential corrections and the protection levels computation were those received in real-time by the receivers or those available off-line from the EDAS server. Finally, 10 different combinations of receivers/antennas/corrections have been evaluated and compared to reference positions provided by a high-grade IMU hybridized with a dual-frequency phase-differential GPS system (LandINS equipment from the IXSEA French Company).

Figure 3 shows the on-board test equipment that was installed on our test vehicle and Table 2 summarizes the 10 different GNSS configurations that have been evaluated.

- The TIM-LH from Ublox is a low-cost high sensitivity receiver, representative of the new generation of GPS chips dedicated to car and pedestrian navigation, capable of EGNOS mode and delivering the code and Doppler raw observables.
- The DLV3-RT2G from Novatel is a high grade bi-frequency geodetic receiver, used here only as a L1 only EGNOS and stand-alone receiver, comparable to medium-price boards of less than 1000 € proposed by the same manufacturer.

- The Trimble Pathfinder PRO-XT is a GIS receiver, representative of the most expansive L1 DGPS products, capable to receive standard RTCM DGPS corrections transmitted from a terrestrial network of reference stations via the cellular communication network. The cost of this receiver (close to 4000 €) is also due to the quality of the multipath mitigation SW embedded inside.

The reference trajectory (also called ground truth) was obtained thanks to the IXSEA LandINS high-grade inertial measurement unit hybridized with kinematic GPS and odometry (3). The accuracy obtained by such a system depends on the length of the satellite unavailability periods and the possibility to compute a post-processed kinematic solution with the bi-frequency receiver. When the PPK GPS is available, the accuracy is of the order of 2-3 cm (95%), when it is unavailable, it can increase up to 15 cm (RMS) after 2 minutes of pure inertial navigation.

DESCRIPTION OF THE TEST CIRCUITS

Different types of circuits had been chosen to reflect both the diversity of the environments (urban, interurban, etc.) and the diversity of the applications (GPS odometer, parking zones control, dangerous goods monitoring, automatic toll collection, etc.). The lengths were between 150 m and 21 km, and the speed of the test vehicle was between zero (for static tests) and 90 kmph. The circuits were located in or around the cities of Nantes, Bordeaux and Lyon. Finally, 12 circuits or locations have been travelled by our test vehicle.

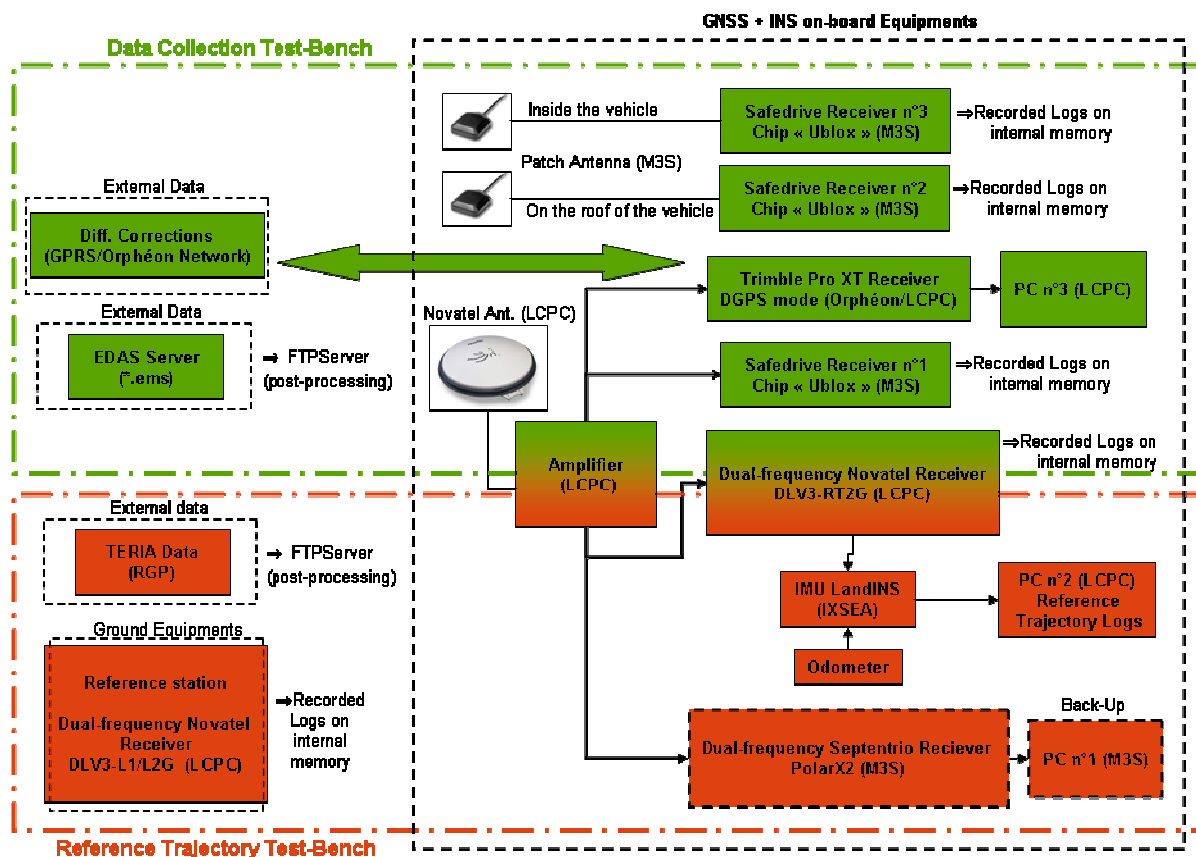


Figure 3. The on-board and ground test equipments

Receiver	Antenna (roof)	L1 PVT solution analyzed
Low cost (100 €) (u-blox TIM-LH in SAFEDRIVE box of M3S)	Low cost (Patch Hirschmann GPS 7M)	C1 : GPS <i>stand-alone</i> C'1 : GPS-EGNOS OS (geo satellite) C''1 : GPS-EGNOS EDAS (ESA EMS server)
	High cost (Novatel GPS-702 GGL)	C2 : GPS <i>stand-alone</i> C'2 : GPS-EGNOS OS (geo satellite) C''2 : GPS-EGNOS EDAS (ESA EMS server)
Medium cost (800 €) (Novatel DLV3-RT2G)	GPS-702 GGL)	C3 : GPS <i>stand-alone</i> C'3 : GPS-EGNOS OS (geo satellite) C''3 : GPS-EGNOS EDAS (ESA EMS server)
High cost (3 700 €) (Trimble Pro XT)		High cost (Novatel)
C4 : DGPS TR through GPRS <i>Orphéon</i> network		

Table 2. The 10 tested GNSS configurations

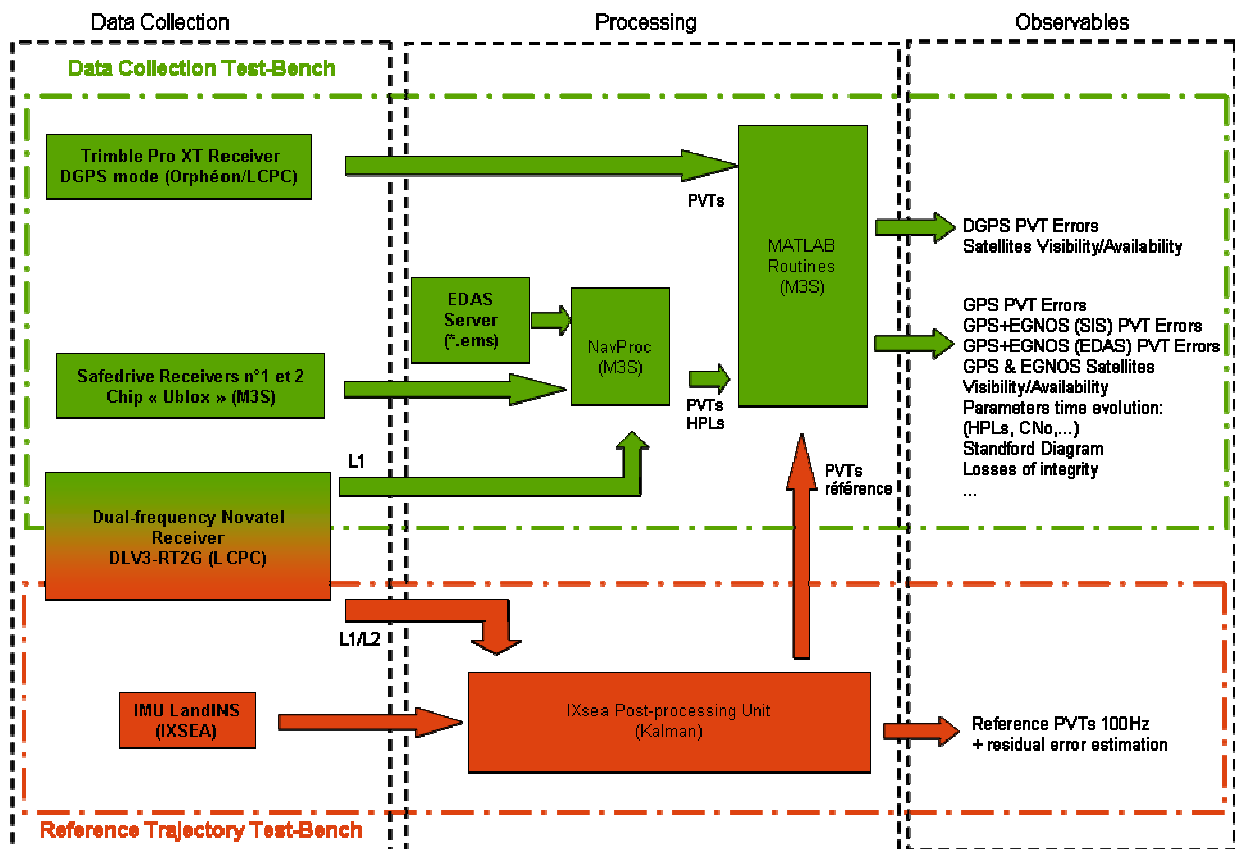


Figure 4. The data processing of the test bench

THE DATA PROCESSING

Three different blocks of data processing were necessary (see Figure 4):

- EGNOS computations: to compute the EGNOS-corrected PVTs (Positions, Velocities and Time) and the HPLs (Horizontal Protection Levels) from the GPS pseudo-ranges and the EGNOS messages, using the MOPS (civil aviation) standard,
- reference trajectory computation, using a GPS post-processing software and the EKF (Extended Kalman Filter) of the LandINS equipment for the data fusion,
- a block of Matlab routines, making use of all the output data of the previous blocks, to compute the statistics on the HPEs (Horizontal Position Errors), the HPLs and the detection of losses of integrity (MI : Misleading Information) obtained for every time step.

The following statistics have been computed, for each GNSS configuration:

- Availability of GPS positioning: percentage of time when the Nb of sat > 3 ,
- 2D HPE (mean, median 50 % and 95 %): *Horizontal Position Error* = horizontal distance between GNSS position and reference position (provided by the LandINS),
- availability of EGNOS mode: percentage of time when EGNOS corrections from at least 1 Geo satellite are received and valid (validity time),
- 2D HPL (mean, median 50 % and 95 %): *Horizontal Protection Level* computed by NavProc software according to the MOPS (4),
- MI rate (*Misleading Information*): percentage of time when $HPE > HPL$,
- NMI rate (*Near Misleading Information*): percentage of time when $HPL > HPE > 0.75 HPL$,
- Very Safe condition rate: percentage of time when there is no MI neither NMI ($0.75 HPL > HPE$).

Two examples of graphs produced by the analysis are presented on Figure 5 below: a Stanford plot and a Safety Index plot, commonly used for integrity performances assessment.

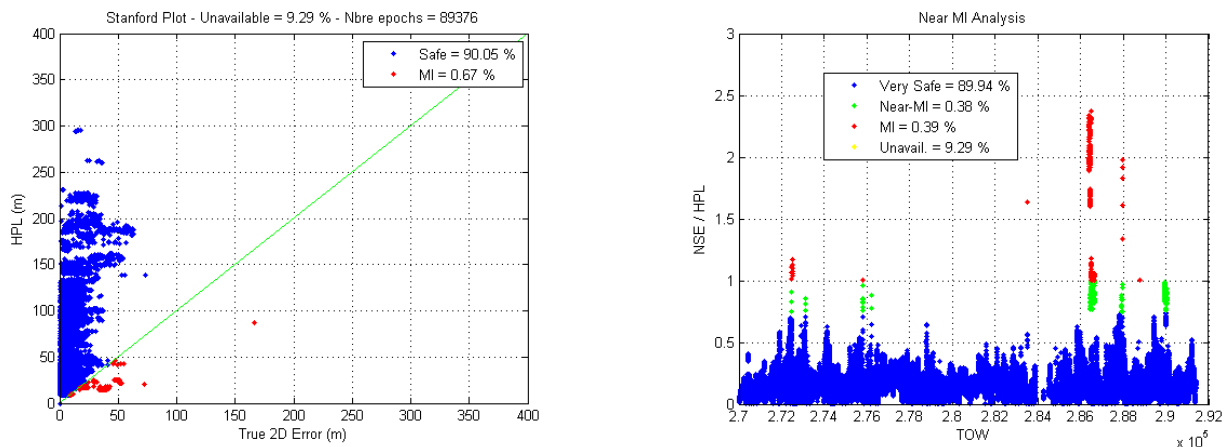


Figure 5. Examples of integrity analysis plots

THE RESULTS

PERFORMANCES IN TERMS OF POSITIONS

A lot of data have been collected, processed and analyzed. It is not possible to survey all the results in a conference paper and below will be given the most relevant ones, under the form of three tables.

These tables show respectively the results for the low-cost (C1 and C'1), the medium cost (C3 and C'3) and high-cost (DGPS C4) configurations (see Table 2) in 4 different types of environments (urban, inter-urban, forest and clear).

Environment	Accuracy (1)		Integrity (2)		Availability	
	GPS	GPS + EGNOS	GPS	GPS + EGNOS	GPS	GPS + EGNOS
Urban	-	+	-	-	+	--
Urban zone Lyon	8.51	- 7 %		3,44 %	97.9 %	29.9 %
Odometer 3 - Nantes	4.13	-10 %		0.26 %	99.4 %	27,3 %
Parking 2 - Nantes	5.07	- 11 %		2.40 %	99.8 %	94.9 %
Parking 3 - Nantes	19.24	- 9 %		68,73 %	99.6 %	95.2 %
Inter-urban	+	++	-	++	+	-
Ring road Bordeaux	3.15	- 13 %		0.03 %	99.1 %	87.7 %
Gantry 1 Lyon	2.64	-13 %		0.01 %	99.8 %	95.6 %
Gantry 2 Lyon	2.39	- 14 %		0 %	98.1 %	72.2 %
Corridor Lyon	2.85	- 7.7 %		0.17 %	98.5 %	64.0 %
Forest	+	++	-	++	++	-
Landes	3.24	-16 %		0.05 %	99.8 %	85.9 %
Odometer 2 - Nantes	5.89	- 32 %		0.13 %	99.6 %	40.8 %
Clear	++	++	-	++	++	++
Odometer 1 - Nantes	2.70	- 3 %		0.3 %	99.7 %	99.4 %
Parking 1 - Nantes	2.33	Idem		0 %	99.8 %	99.8 %

(1) Mean horizontal position errors (m)

(2) (MI + NMI) rate (HPE > 0.75 HPL)

Table 3. Synthetic results for the low-cost configurations C1 & C'1

It can be seen from Table 3 that standard low-cost GPS receiver accuracy can be quite interesting in clear environments (HPE = 2.33 m), but is rapidly degraded as soon as the environment is constrained and subject to multi-path effects (19.24 m).

About accuracy, it can be seen in the third column that the relative gain brought by EGNOS (OS or EDAS) is rather small: between 3 % and 32 %, in general of the order of 13 %. For the last 2 scenarios, the gain is even null or non significant.

As far as integrity is concerned, it can be seen that the HPL computed following the MOPS standard is still significant and relevant in most of the environments, except the urban ones, since the (MI + NMI) rate remains very close to zero.

About availability, GPS availability remains good in every case, but EGNOS-OS availability can be very poor in urban or forest environments.

Generally speaking, EGNOS-EDAS performances are not significantly different than the ones from EGNOS-OS, except for availability, which is kept at 100 %.

Environment	Accuracy (1)		Integrity (2)		Availability	
	GPS	GPS + EGNOS	GPS	GPS + EGNOS	GPS (1)	GPS + EGNOS
Urban	-	++	-	-	-	--
Urban zone Lyon	5.30	- 17 %		2.18 %	74.7 %	25.5 %
Odometer 3 - Nantes	3.02	- 7 %		0 %	84.2 %	40.3 %
Parking 2 - Nantes	2.25	- 20 %		1.25 %	83.5 %	82.7 %
Parking 3 - Nantes	13.41	- 11%		57.51 %	85 %	83.4 %
Inter-urban	++	+++	-	++	-	--
Ring road Bordeaux	1.45	- 16 %		0.01 %	83.2 %	76.8 %
Gantry 1 Lyon	2.41	- 53 %		0 %	88.0 %	77.2 %
Gantry 2 Lyon	1.14	- 18 %		0.07 %	86.9 %	54.9 %
Corridor Lyon	1.31	- 15 %		0.03 %	79.5 %	61.9 %
Forest	++	+++	-	+++	-	--
Landes	1.81	- 26 %		0 %	87.1 %	62.7 %
Odometer 2 - Nantes	2.22	- 12 %		0 %	84.4 %	36.9 %
Clear	+++	+++	-	+++	-	-
Odometer 1 - Nantes	0.94	+ 29 %		0 %	95.7 %	95.0 %
Parking 1 - Nantes	0.72	Idem		0 %	87.2 %	87.2 %

Table 4. Synthetic results for the medium-cost configurations C3 & C'3

For medium-cost configurations, it can be seen from Table 4 that all the main tendencies expressed for low-cost are still valid, even if the numbers are different, accordingly to the quality of the receivers.

On accuracy, it can be noticed that, even if the gain brought by EGNOS seems a little bigger here, we experienced one case where the accuracy of EGNOS solution was below the stand-alone GPS accuracy, probably due to a different choice of satellites for the computation algorithms and an already excellent GPS solution.

The remarks about good EGNOS integrity for all the scenarios except urban ones and on poor EGNOS availability in urban environments remain valid.

Environment	Accuracy		Integrity		Availability	
	DGPS	GPS + EGNOS	GPS	GPS + EGNOS	DGPS	GPS + EGNOS
Urban	+++		-	-	-/++	
Urban zone Lyon	1.59				80.2 %	
Odometer 3 - Nantes	1.10				73.9 %	
Parking 2 - Nantes	0.77				100 %	
Parking 3 - Nantes	1.03				100 %	
Inter-urban	+++		-	-	-/+	
Ring road Bordeaux	0.85				99.9 %	
Gantry 1 Lyon	0.65				99.1 %	
Gantry 2 Lyon	1.11				95.1 %	
Corridor Lyon	1.13				95.2 %	
Forest	+++		-	-	-/+	
Landes	1.01				99.1 %	
Odometer 2 - Nantes	1.05				94.5 %	
Clear	++++		-	-	+++	
Odometer 1 - Nantes	0.56				100 %	
Parking 1 - Nantes	0.51				100 %	

Table 5. Synthetic results for the high-cost configuration C4

The results reported in this table, obtained from the GIS-oriented DGPS system operated with differential corrections are very different from the previous ones. Only numbers about accuracy are reported and have to be compared to the GPS and GPS + EGNOS numbers of the previous tables, because this receiver offers no possibility to compute any HPL.

We can see very easily that the results in terms of accuracy are much better than any previous configuration, even if some results of the C'3 are quite close in some rather clear environments. What is really significant here is the excellent behaviour of this system in urban environments, highlighting the good performances of the embedded firmware for multi-path mitigation.

PERFORMANCES WITH RESPECT TO THE SERVICES

Then, we considered the achieved performances in terms of position with respect to the global criteria we assigned to the applications at the beginning of the project. For the Odometer and Parking services, we had to develop simple application programs to be able to assess the overall adequacy of the positioning systems to the expectations of the users.

Table 6 below shows the results of this adequacy analysis.

Applications	Configuration	Environment			
		Urban	Interurban	Forest	Clear
Odometer Error < 1% distance	C1	NO		NO	NO
	C'1	NO		NO	NO
	C3	NO		NO	NO
	C'3	NO		NO	NO
	C4	NO		NO	YES
Parking Bias < 1.9 m & R50 < 2 m after 30 mn	C1	NO			NO
	C'1	NO			NO
	C3	YES			YES
	C'3	YES			YES
	C4	YES			YES
Geofencing R95 < 3 m	C1	NO	NO	NO	NO
	C'1	NO	NO	NO	NO
	C3	NO	NO	NO	YES
	C'3	NO	YES	NO	YES
	C4	YES	YES	YES	YES

Table 6. Adequacy of the GNSS configurations to the targeted services

From this table, it can be extracted the main following results:

- the Odometer application needs, with the chosen criteria, is fulfilled only with high-cost configuration in clear environments,
- the Parking application needs can be fulfilled with medium-cost receivers, whatever their mode, stand-alone or EGNOS-corrected,
- as far as Geofencing applications are concerned, the results depend again on the environment.

These results have to be carefully considered since they depend a lot on the adequacy criteria chosen and of the application algorithms efficiency. It is clear that more sophisticated algorithms than the ones used here would lead to much better performances in general. However, the relative results of the study are still valid, whatever the algorithms efficiency.

CONCLUSIONS

The main conclusions of the study are the following.

- The performances are strongly correlated to the price of the equipment.
- In terms of pure horizontal accuracy, the gain brought by EGNOS corrections to stand-alone GPS in road environments is relatively moderate, between 10% and 30%, and does not significantly improve the adequacy of the GNSS receiver with respect to the services, the difference being made by the quality of the receiver.

- Terrestrial differential corrections (i.e. those we used, elaborated by the ORPHEON network and brought by cellular network to the receiver) seem significantly more efficient, with a mean error 2 to 3 times smaller than the EGNOS one.
- Multi-paths, not mitigated by EGNOS corrections, and especially non-line-of-sight multi-paths, are mainly responsible for the accuracy degradation, an efficient multi-path mitigation firmware is necessary to keep the mean accuracy around 1 m.
- The availability of geostationary satellites EGNOS corrections is generally acceptable, except in urban areas where other means of transmission are necessary (i.e. EDAS).
- The main added value of EGNOS is definitely its integrity features, e.g. the information in the messages that allows the computation of the *Protection Levels*.
- In relatively open environments, the HPLs computed by applying the MOPS standard (designed for airplane environments) are quite relevant and allow a good protection of the vehicle, but they lose rapidly their significance as soon as the multi-paths effect increases, meaning clearly that the MOPS standard is not applicable for road environments.
- Present low-cost stand-alone GPS receivers, or low-cost EGNOS-corrected GPS receivers are not accurate enough to be widely used in Geofencing applications that require a high accuracy (i.e. a mean error < 1 m). Only medium cost EGNOS-corrected receivers with good antenna can reach this accuracy in open environments and high cost DGPS receivers in all kinds of environments.

RECOMMENDATIONS

About accuracy, the “killer” equipment will be the one capable to receive good differential corrections 100% of the time with efficient multi-path mitigation software inside.

About integrity, more adapted FDE (Fault Detection and Exclusion) and HPL computation methods are required, taking into account the low number of satellites in view, and probably making use of additional navigation sensors and a good knowledge of the 3D environment.

REFERENCES

(1) URL: <http://www.essp-sas.eu/home>

(2) URL: http://www.esa.int/esaNA/GGGQI950NDC_egnos_0.html

(3) Duchâteau, G. and Nouvel O and Vigneau W and Bétaille D and Peyret F and Secrétan H, "How to assess and improve satellite positioning performances in urban environments", in *Proceedings of ITS World Congress* (Stockholm, September 09)

Smith, A and Jones, B, in *Proceedings of Conference* (Location, Date), Publisher

(4) "MOPS for Global positioning system/wide area augmentation system airborne equipment", RTCA standards, DO229C, 28 November 2001