# Improving vehicles positioning using wireless telecommunication media and GNSS hybridization

D. Bonacci, W. Chauvet, P. Paimblanc and F. Castanié
TeSA, Telecommunications, Space and Aeronautics
14-16 Port Saint Etienne, 31000 Toulouse, France
David.Bonacci,Wilfried.Chauvet,Philippe.Paimblanc,Francis.Castanie@tesa.prd.fr

***Index Terms*— GNSS, Wireless, Telecommunications, hybridization, high resolution, parametric modeling.**

## I. Introduction

THE problem of geopositioning is of primary interest in order to carry out a large variety of applications such as companies' vehicles fleet tracking, emergency calls regulations (E911 in the US and E112 in Europe), mountain and seaborne rescue or positioning of dependent persons (children, ageing people) and animals. Performances of positioning systems, such as Global Navigation Satellite Systems (GNSS), are usually quantified or qualified through 4 notions: accuracy, availability, continuity and integrity. These performances are mainly affected in urban and indoor environments due to possible masking of satellites by buildings and multipath effects.

Within this framework, TESA laboratory works simultaneously on two projects: FIL (Information Fusion for Localization) and TRANSCONTROL (control and follow-up of dangerous goods transportation). This paper shows how it is possible to increase satellite-based positioning systems performances, at least in terms of accuracy and availability by using hybridization with wireless telecommunication systems (such as GSM, Wifi, UWB and DVB television signals) that are often widely deployed in urban and indoor environments.

Rather than simply transmitting to the receiver information easing satellite signals acquisition as Assisted GPS (A-GPS) does, the purpose is to use information given in GSM and Wifi beacon frames (such as timestamps, emitted and received power) and triangulation techniques. There are three main classes of methods in the literature:

- AOA (Angle Of Arrival). This method is not accurate enough and can be considered as a help for the two following kinds of methods.
- DTOA (Difference Time Of Arrival). This method consists in measuring the duration of the path of the electromagnetic wave (moving at light speed) between the emitting antenna and the receiver and to apply then triangulation techniques.
- Methods based on received electromagnetic signals powers: they can be splitted in 2 subfamilies: methods based on a database containing a power profile (only applicable indoors in an immobile environment) and methods based on the use of a propagation model and triangulation. This last sub-family of methods is more complex and costs more computational time but is much more adaptative regarding environmental changes.

Main scientific issues are ambitious:

- Problems of synchronization with the DTOA method (measured values are of the order of the nanosecond).
- Multipath effects and possible difficulties in identifying the direct path.
- Hybridization brings a complex theoretical problem: find a way to best mix several kinds of measurements (such as GNSS pseudoranges, received powers or times of arrival) by automatically assigning a reliability index to these measurements.

## II. Problem formulation

### A. GNSS Measurement model

GNSS positioning is based on triangulation (or circular positioning): the distances between user and satellites are obtained by multiplying travel time by the speed of light, and expressed as functions of the satellites' and user's coordinates. Travel time is measured by comparing the time of emission (provided by the satellite) and the time of reception (measured by the user). Satellite clocks can be synchronized with a global GNSS time using information contained in the navigation message broadcast by the satellites themselves. However, the offset between the user's clock and GNSS time cannot be predicted and needs to be estimated at the same time as his position. Thus, the GNSS measurements that are actually processed by the positioning algorithm are not ranges but rather *pseudoranges*, which have the following structure [1]:

$$y^i = \rho^i + c\Delta t_u + \epsilon^i \tag{1}$$

where:

- $\rho^i$ is the true geometrical distance between the satellite antenna and the user receiver antenna,
- $\Delta t_u$ is the user receiver clock offset with regard to GNSS time,
- $\epsilon^i$ is the sum of the measurement errors due to multipath, background interference, noise, ionospheric and atmospheric propagation delay residuals, satellite clock residuals.

For the present article, the pseudorange measurements were generated. Realistic satellite trajectories were simulated through the use of YUMA ephemeris data and used to compute pseudoranges based on the theoretical user position and clock bias. A simple noise model has been used: $\epsilon_i$ was considered to be Gaussian, with a standard deviation function based on the satellite's elevation from the user's point of view[2]:

$$\sqrt{a + \frac{b}{\tan^2(\alpha_i)}}.$$

where $\alpha_i$ is the elevation of satellite $i$. This model is illustrated in figure 1. Since there are four unknowns (the user's coordinates plus his clock bias), there must be at least 4 available satellites for a navigation solution to be computed. Although this number is guaranteed to be reached in open space, it is often not met in more restricted environments such as urban areas. Thus, GNSS measurements are to be complemented with power measurements performed on GSM signals.

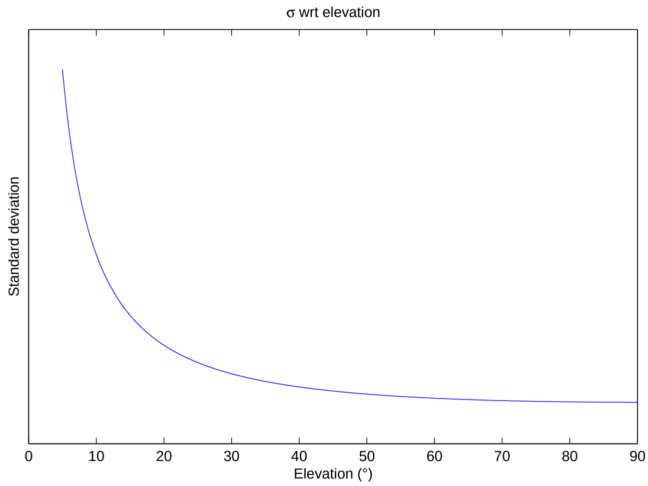


Fig. 1. Evolution of standard deviation with regards to satellite elevation

### B. GSM channel model

In a GSM network, BTS (Base Transceiver Station) continuously transmit a beacon signal. The power of this signal is received by the mobile and allows the mobile to choose the BTS with the most powerful signal in order to get a communication. We propose to use the power of this continuous signal for positioning purpose. When propagating in a free space, RF signal is subject to an attenuation given by the Friis Formula [3]:

$$P_r = P_e G_e \left(\frac{\lambda}{4\pi d}\right)^2 G_r \tag{2}$$

where:

- $P_r$: received power at user antenna (W)
- $G_e$: linear gain of the emitter antenna
- $\lambda$: wavelength (m)
- $d$: distance between emitter and receiver (m)
- $G_r$: linear gain of the adapted receiver

In the following of this paper, we make the assumption that there is a Line Of Sight (LOS) between the mobile and the BTS. Therefore, the direct path is attenuated according to the Friis formula because of the free space path loss. In addition, we will consider the shadowing phenomenon. This effect is caused by the propagation of the microwave through obstacles. Shadowing is illustrated by figure 2. Shadowing phenomena lead to the product of independent attenuations and can be modeled by a lognormal distribution. As a consequence, received power is the power given by equation 2, but affected by a lognormal multiplicative attenuation. In the following, parameters of this distribution will be $\alpha$ and $\beta$, such that the shadowing is generated by $10log_{10}(X)$ where X is distributed according to a Gaussian distribution $N(\alpha, \beta)$.
Value of $\alpha$ and $\beta$ are statistical values that are estimated by experimental results. These values strongly

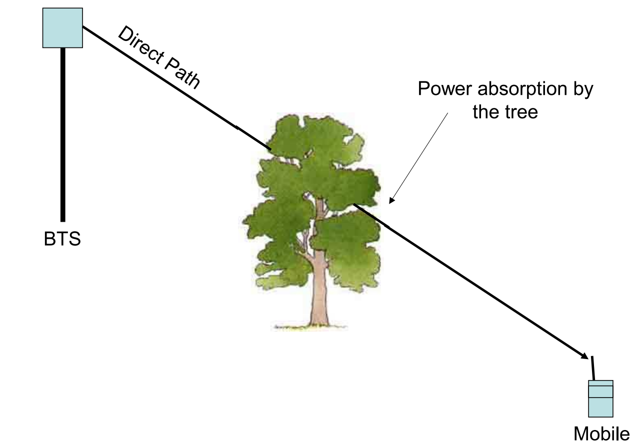


Fig. 2. Shadowing effects on the direct path

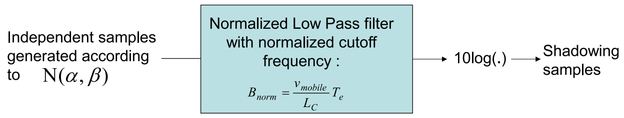


Fig. 3. Shadowing simulator

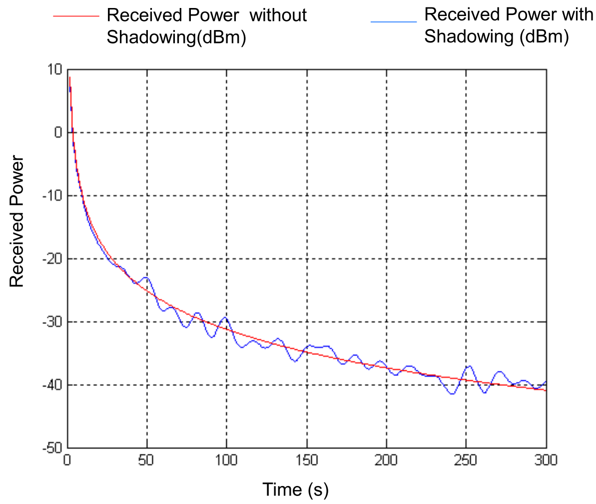


Fig. 4. Power profile including shadowing

depend on the type of environment (urban, suburban, country). According to the literature, when the mobile is going accross country, we will choose 0 dB for $\beta$ parameter (variance) in the simulations [3] (mean $\alpha$ is supposed to be null). In an urban environment, channel model becomes more complex because multipath have to be taken into account leading to a Rayleigh or Rice model depending on the power of the multipath [4]. Such a scenario will be considered in a forthcoming paper.
In addition, shadowing phenomenon depends on the local environment of the mobile. As a consequence, there is a correlation distance for the shadowing: $L_c$. This coherence value is a statistical value that gives an indication on how far the mobile has to move to get a new value of shadowing realization and also depends on the environment. Another parameter is the sampling period $T_e$ for the power measurement. Simulator of the shadowing effect is given by figure 3. As an illustration of the shadowing effect on the received power, we plot the received power of a mobile going away from a BTS with a speed $v_{mobile} = 50$ km.h$^{-1}$ on figure 4. Received power is given in dBm (logarithmic relative power for a reference power of 1 mW).

The numerical values for simulations are:

- Parameters for BTS:
  - $P_e = 45.5$ dBm (35W). This value of emitted power is typical value of BTS of power Class 4 [5].
  - $Ge = 17$ dBi (value for a trisectorized antenna)
  - $\lambda = 33$ cm (value for a GSM frequency of 900MHz)
- Parameters for channel :
  - $\alpha = 0$
  - $\beta = 0$ dB
  - $L_c = 100$ m
- Parameters for mobile :
  - $Gr = 0$ dBi
  - $v_{mobile} = 50$ km.h$^{-1}$.
  - $T_e = 1$ s.

### C. *performance criteria*

The addition of GSM power measurements to the positioning algorithm is expected to increase performance levels on two aspects: *accuracy* and *availability*. Their practical definition will be derived from the formulations used in civil aviation:

- **Accuracy:** it is the degree of conformance between the estimated or measured position and/or velocity of a platform at a given time and its true position and/or velocity.
- **Availability:** it is the ability of the navigation system to provide the required function and performance at the initiation of the intended operation. It is expressed as a percentage of time.

### D. *GNSS-GSM Particle-Filter fusion algorithm*

Realtime estimation and fusion has been widely implemented using the Kalman Filter [6] (or one of its numerous variants) for several decades because this technique requires a few computational power in comparison to more modern techniques like for instance particle filtering.

Now that computational power is more available, one can benefit from non-linear filtering techniques (see [7] for a presentation). In addition to optimal non-linear modeling, they allow to treat optimally the presence of non gaussian noise on observations or state transition equations. This is particularly convenient for state transition noise because some *a priori* information on the pdf (probability density function) can be included by this way. The observation noise can often be considered as gaussian, due to the Central Limit Theorem. Moreover, these non linear filtering techniques are suited directly to a large variety of physical equations (often non linear) whereas Kalman filter requires linearizations that can be inaccurate in some situations. Positioning algorithms are a perfect example where the system experiences abrupt changes because the number of satellites in sight can vary over time.

Under Markov assumptions, the joint probability distribution between states and observations depends only on the state transition probabilities and observation probabilities. As a consequence, evolution and observation models have to be determined. We have considered here an identity evolution model perturbated by white gaussian noise and a non-linear observation model given by the concatenation of equations (1) and (2).

This problem involves the estimation of hidden variables (target position coordinates) thanks to observations. More precisely, 4 variables have to be estimated and compose the particle filter state vector:

- $x_t$, $y_t$ and $z_t$: the target coordinates in ECEF (Earth-Centered, Earth-Fixed) Cartesian coordinate system.
- $\Delta t_u$, the user receiver clock offset with regard to GNSS time (depends only on the user's receiver).

The state vector can be decomposed into 2 blocks of variables: the first one is composed of the user's coordinates $x_t$, $y_t$ and $z_t$ and the second one is the user receiver clock offset $\Delta t_u$. Conditionally to the first block, the second one appears as a linear gaussian structure. In these conditions, it is possible to implement an efficient particle filtering strategy called "Rao-Blackwellisation" for which the linear part of the model is resolved analytically by Kalman filtering. The Rao-Blackwellised particle filtering has been presented independently in [8] and [9]. It allows to significantly reduce the variance of the estimates in the case of such models (conditionally linear gaussian) by reducing the dimension of the vector estimated by particle filtering.

Fig. 5. Simulations scenario

## III. Simulations

### A. *Framework of the simulations:*

In the first section, two Telecommunication Positioning Method (TPM) were presented, namely the DTOA and the RP Methods. The purpose of these methods is to provide additional information in order to improve accuracy and integrity of the GNSS position. Hybridization of these extra data with the GNSS position has to be processed relying on the Particle Filter data fusion algorithm.

The following scenario is envisaged: A vehicle is moving straight on a road in the south of France towards "Fos sur Mer" from point A to point B. 7 BTS are placed along the road as shown in figure 5 and their exact position is supposed to be known. The distance between point A and point B is 9456 m and the vehicle, starting from point A, gets point B in 720 seconds (its speed is constant and around 50 km/h). We propose to investigate a positioning solution based on GNSS pseudoranges and GSM Received Power. This method does not require extra equipment since it only relies on the received power of the GSM mobile. Hence, we make the assumption that the vehicle is able to measure separately the received power of signals emitted by several BTS of the GSM network. Two different scenarios are considered. The first one points out the improvement in terms of accuracy when additional GSM received powers are provided. The second one aims at showing how the use of additional GSM measurements impacts the levels of availability of the global system.

Scenario 1: 5 GNSS satellites are in sight. 7 BTS are also in sight. For such a scenario, each of the GNSS satellites provides a pseudorange. This number of satellites would be sufficient to get a position of the vehicle. But we propose an hybridization of the GNSS pseudoranges with the GSM powers. We propose to use a particular filter as an hybridization algorithm. Observation equation of the particle filter will integrate the models for GNSS pseudoranges and free space loss for GSM powers (cf equations (2) and (1)). Simulations are performed in order to compare positioning accuracy with and without the use of the GSM powers.

Scenario 2: At the beginning of the trajectory, 5 GNSS satellites are in sight and 7 BTS are also in sight as in the first scenario. Between $t = 200$ s and $t = 400$ s, it is supposed that no GNSS pseudorange measurement is available and the determination of the position of the receiver is then not possible using only GNSS system. However, positioning through GSM powers remains possible through the Particle Filter Fusion Algorithm as in the first scenario. Simulations are performed in order to show how the level of availability can be increased thanks to the GSM powers.

### B. *Simulations results*

With respect to scenario 1, simulations have shown that the use of GSM powers in addition to GNSS pseudoranges can improve positioning results in terms of accuracy as shown in figures 6 and 7 where are depicted the estimation error given by the norm of the vector formed by the difference between the true simulated position and the estimated one.

The second scenario aims to show the improvement brought by the GNSS and GSM measurement fusion in terms of availability. Between $t = 200$ s and $t = 400$ s, the GNSS positioning system is not available and is replaced by the position derived from GSM power measurements. It can be noted that, even if the error is far larger, a position estimate is still available (see figure 8).

## IV. Conclusions

The aim of this paper was to propose a way of improving the positioning performance of the GNSS system through hybridization with distances derived from GSM power measurements. Both GNSS and GSM measurements were generated using simulation

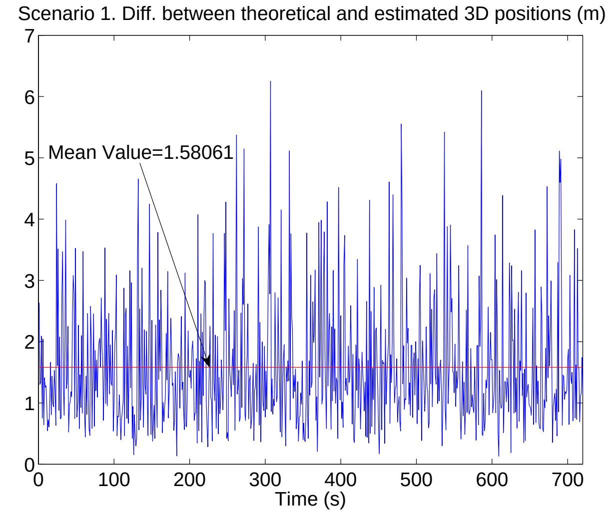


Fig. 6. Positioning error vs time for scenario 1 without GSM powers

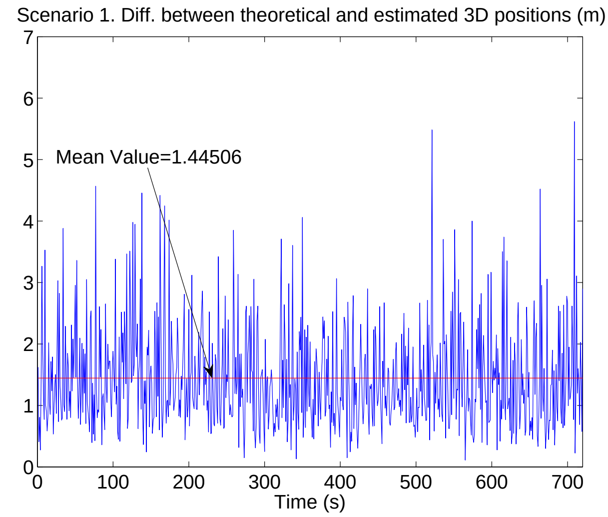


Fig. 7. Positioning error vs time for scenario 1 with 7 GSM BTS in sight

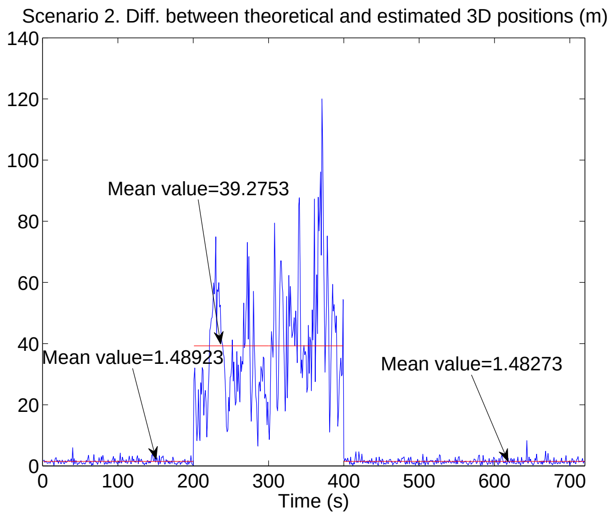


Fig. 8. Positioning error vs time for scenario 2 with 7 GSM BTS in sight and 0 satellite available between $t = 200$ and $t = 400$ s

models. The algorithm chosen to perform the hybridization is a particle filter. Simulations showed that while accuracy can only be slightly improved, a position solution can be obtained even when the GNSS system is not available, thus considerably improving availability. Urban scenarios are now under study. In such a context, GSM channel becomes more complex since multipath can not be disregarded but this drawback can be mitigated by a higher density of BTS in urban environment.


## ACKNOWLEDGMENTS

The authors are indebted to the ANR (French National Agency for Research), the DGE (Direction Générale des Entreprises), the Midi-Pyrénées region and the 'Grand-Toulouse' administrative districts community for their financial support through the FIL and TRANSCONTROL programs.


## REFERENCES


[1] B.W. Parkinson, J.J. Spilker Jr., P. Axelrad, and P. Enge, *Global Positioning System: Theory and Applications Volume I*, American Institute of Aeronautics & Astronautics, June 1996.

[2] P. Paimblanc, C. Macabiau, B. Lobert, M. Van Den Bossche, and S. Lannelongue, "Implementation of robust algorithms in the Galileo integrity monitoring concept," in *Proceedings of the ION GNSS 18$^{th}$ International Meeting*. Institute Of Navigation, September 2005.

[3] Simon S. Saunders, *Antennas and propagation for wireless communication systems*, Wiley, 1999.

[4] M. Patzold, U. Killat, F. Laue, and Y.Li, "On the statistical properties of deterministic simulation models for mobile fading channels," *IEEE Trans on Vehicular Technology*, vol. 47, no. 1, 1998.

[5] Technical Specification Group GSM/EDGE, *3GPP TS 45.005 V7.12.0 Radio Access Network, Radio transmission and reception*, 3rd Generation, Partnership Project, November 2007.

[6] R. Kalman, "A new approach to linear filtering and prediction problems," *Trans. ASME*, pp. 35–45, 1960.

[7] A. Doucet, N. de Freitas, and N. Gordon, *Sequential Monte Carlo Methods in Practice*, Springer, New York, 2001.

[8] R. Chen and S.J. Liu, "Mixture kalman filters," *Journal of the Royal Statistical Society*, vol. 62, no. 3, pp. 493–508, 2000.

[9] A. Doucet and C. Andrieu, "Particle filtering for partially observed gaussian state space models," *Journal of the Royal Statistical Society*, vol. 64, no. 4, pp. 827–836, 2002.


**David Bonacci** was born in 1974. He got his Engineer degree from ENSEEIHT in 1999, his Ph.D. from National Polytechnics Institute of Toulouse in 2003. He is now a Research Engineer at the TESA Laboratory since 2005. He teaches essentially adaptive and classical Signal Processing at the undergraduate and graduate level. His research activity is centered around radar, parametric modelings, subband decomposition, positioning and particle filtering.

**Wilfried Chauvet** was born in 1976 in France. He got his Engineer degree from INT (National Institute of Telecommunications), his Ph.d from National Polytechnics Institute of Toulouse in 2004. He is now Research Engineer at the TESA Laboratory. His research field is Signal Processing in Telecommunications.

**Philippe Paimblanc** graduated as an electronics engineer from the ENAC (Ecole Nationale de l'Aviation Civile) in 2002 and received the same year his Master research degree in signal processing. He performed a PhD at the satellite navigation lab of the ENAC. He is now a research engineer at TéSA laboratory, in Toulouse, France.

**Prof. Francis Castanié** has got his Ph. D and its Doctorate of Sciences degree from National Polytechnics Institute of Toulouse (INPT) respectively in 1971 and 1977. He teaches essentially Signal Processing at the undergraduate and graduate level. He gives several doctoral courses in the following topics: Time-Frequency and Wavelet Analysis, Parametric Signal and Time Series Modeling, Digital Signal Processing. Prof. Castanié is the Director of the Research Laboratory Telecommunications for Space and Aeronautics (TeSA). Together with this activity in TeSA, he joined the CNRS Institut de Recherche en Informatique de Toulouse (IRIT) in 2002, where he is heading the Signal and Communication Group. He has several responsibilities in research societies at the national level (SEE) and at the international level: he had been Chairman of the French Chapter of Signal Processing of the IEEE, from 1992 to 2002. He authored or co-authored more than 52 papers (among which an International First Prize and a Best Paper Award), and more than 240 communications in international conferences. He has 7 international patents, and has co-authored around 99 industrial contracts reports. During his 30 years of career, he has been the advisor of more than 60 Ph. D. students.