The SaPPART COST Action: Towards Positioning Integrity for Road Transport

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***Abstract*— Global Navigation Satellite Systems (GNSS) is becoming one of the main components supporting Intelligent Transport Systems (ITS) and value-added services in road transport and personal mobility. The use of GNSS is expected to grow significantly due to improvements in positioning performance, with positive impacts such as: finding the optimal route; improving traffic and travel efficiency as well as safety and security; reducing congestion and optimizing fuel consumption. The deployment of mission critical applications needs high reliability in the positioning information. However, the positioning reliability is not easy to achieve because of the heterogeneous quality of the GNSS signal, which is highly influenced by the road environment and the operational scenario of the application. It is important to understand the requirements and performance GNSS can achieve for various road transport applications.**

This paper is presenting the SaPPART COST Action on the Satellite Positioning Performance Assessment for Road Transport. It introduces the goal and the framework of the Action with the research programme and some related activities dedicated to dissemination and supporting standardisation working groups.

Keywords—GNSS; positioning integrity; intelligent transport systems; SaPPART

I. Introduction

Positioning is playing a key role in many applications of the road sector and in mobility services. Most of non-critical applications rely on locations based on Global Navigation Satellite Systems (GNSS) which is appropriate in many situations with limited impacts when the positioning signal is degraded or not available. GNSS have a huge potential in the development of ITS services and the road sector represents 40% of the satellite-based positioning market in term of cumulative core revenue (2013-2023). However, the deployment of very demanding applications does not rely on GNSS receivers because of the complexity of defining and assessing the positioning quality which is highly influenced by the road environment and the operational scenario of the application (Figure 1). Recently some standardisation activities have been initiated in Europe on the topic of positioning performance assessment even if many scientific issues are still open and need a common understanding.

In this context a network of European experts has defined a COST Action within the transport and urban domain called "Satellite Positioning Performance Assessment for Road Transport (SaPPART)". This Action gathers scientists, industrial and governmental partners from the GNSS community and the ITS domain, with the capacity to act for a common goal on the definition of positioning integrity in the road sector [1]. They will address together the open issues and guarantee the success of the standardisation for underpinning certification initiatives. This framework is expected to pave the way for certified positioning terminals, which is expected to result in a significantly accelerated use of GNSS-based ITS and mobility applications.

This paper about SaPPART will first describe the main goals of the Action and its related work programme. Then it will clarify the role of positioning in a series of road application and will present the concept for a positioning terminal. Finally, the paper will highlight the link of SaPPART with standardisation activities.

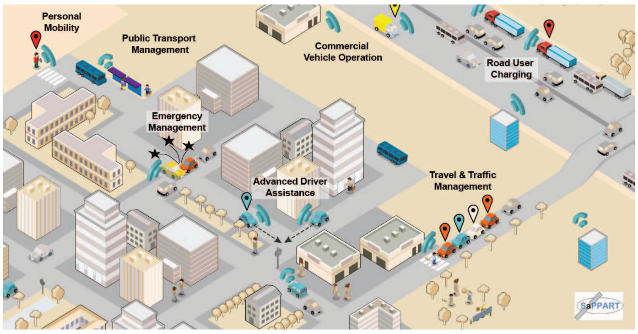

Fig. 1. Overview of location-based services in city [3]

II. Overview of the Action

A. *Framework of the Action*

COST is the European Cooperation in Science and Technology with the aim to enable break-through scientific developments leading to new concepts and products. It thereby contributes to strengthen Europe's research and innovation capacities. [2]

The main goal of the SaPPART Action is the provision of a comprehensive framework for an adequate use of positioning systems for very demanding road applications, like. Road User Charging (RUC), Pay-As-You-Drive insurance, emergency call (eCall), tracking and tracing of dangerous good, Advanced Driver Assistance Systems (ADAS) and autonomous driving. SaPPART is gathering world-wide and European experts from year 2014 to 2017 with the following capabilities:

- to act as a scientific reference centre and to link any specific problem with the best European research team possessing the necessary expertise to solve it
- to support all initiatives aiming at making use of GNSS systems for road transport and personal mobility services in difficult conditions, providing them with reference documents and guidelines for implementing their specific GNSS application
- to propose a comprehensive framework for the definition of the performances of the GNSS-based positioning terminals used in ITS and personal mobility, and the necessary test procedures to assess these performances
- to contribute to a better understanding of the potential and limitations of GNSS in the road transport and personal mobility sectors

The original aspect of such a COST Action is based on the joint work of two different communities who declared to share a common vision on the appropriate use of GNSS in the road sector. In order to achieve this goal, SaPPART Action is defined, as it is aimed at:

- developing a framework for definition of service levels for the GNSS-based positioning terminals, used in ITS and Personal Mobility applications;
- promoting high-level educational and training programmes in the fields of GNSS, GNSS-based ITS and Personal Mobility applications
- promoting the use of GNSS in general, and EGNOS and Galileo in particular, in ITS and Personal Mobility domains, for their common long-term development and deployment in Europe

B. *Goal of SaPPART*

The core group of the members of SaPPART is composed of experts involved in research activity and in CEN Standardisation working groups. The participation in the main European research activity in GNSS for road within the framework programmes FP6 and FP7 has built a strong foundation for SaPPART. The valorisation of this research capital and the capability to link these valuable resources with ongoing and future standardisation activity will promote the SaPPART network with the following goals:

- Capitalizing the main results of a number of National, European and International projects that addressed the use of GNSS in the road sector
- Coordinating European scientists to highlight problems and open issues, strength and weaknesses of GNSS solutions envisaged in different applications
- Developing a framework for the definition of service levels for the GNSS-based positioning terminals and the associated examination framework for certification purposes. This will be in form of guidelines and data sets, which will constitute major inputs to the related European standardisation activities for GNSS-based mobility and transportation services
- Linking the academic community and stakeholders to standardisation bodies (ETSI, CEN, ISO, national standardisation bodies)
- Supporting European-related legislation activities
- Organizing a high-level education and training programme
- Promoting a widespread, advanced and effective use of GNSS in ITS and personal mobility services

C. *Work program*

The main activity of SaPPART is defined in a work programme supported by groups of experts and delegates from the participating countries. The research agenda is composed of three work packages (WP) representing the different roles of positioning within the ITS services. These interconnected WPs can be separated in three main levels: application, positioning terminal and operational scenario. The tasks of the three WPs have been allocated to two working groups and two task forces have been created for the dissemination of the Action and for the support to standardisation and certification.

1) Application level

The application level gathers the operational tools used in the ITS services. The main tasks of SaPPART at the application level are:

- Identification and classification of the main road transport applications making use of location information based on GNSS, of their needs in terms of positioning data. The role and impact of GNSS positions associated with mapping data is also carefully studied since they are widely used in most of the ITS services
- Review of the existing standardisation and certification processes and coordination of the capture of new information for the applications that are not covered
- Identification of the applicative variables and Key Performance Indicators (KPIs) of the applications. The applicative variable is defined as relevant for the application, computed by itself from the output of the positioning terminal, i.e. a road segment, or the detection of a vehicle passing under a virtual gantry, or a travelled distance, etc. The KPIs are the performances expected for these applicative variables (e.g. low rates of missed detection and false detections for RUC systems based on virtual gantry (Figure 2)). Links between the requirements of the application and integrity of the position itself will also be studied
- Proposition of simulation models aiming at modelling the processes applied by the road transport applications. These simulation models are necessary to study the influence of the quality of the positioning information on the KPIs of the application

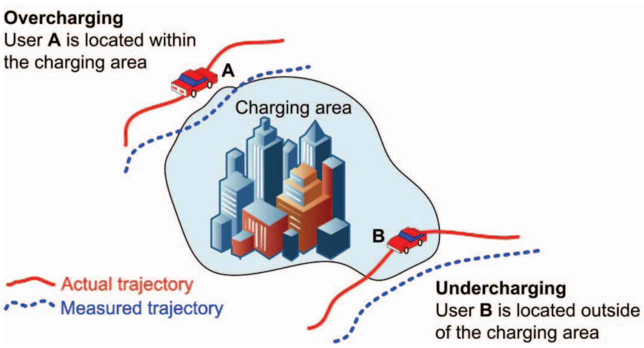

Fig. 2. Example of the impact of positioning in Road User Charging [3]

2) Positioning terminal level

The positioning terminal level is composed of the main components used for the determination of positions in time and space. The main tasks of SaPPART at the positioning terminal level are:

- Analysis of the different possible configurations and architectures of GNSS-based positioning terminals used in road transport applications
- Definition of the positioning variables available from the GNSS-based positioning terminals (position, velocity, time, raw measurements), of the most suitable performance metrics (ways of measuring this performance) and proposition of different positioning service levels in terms of availability, accuracy and integrity.
- Review and enhancement of the existing degradation and error models for the positioning variables (PVT). The definition of the degradation models is necessary for the operational level tasks.

3) Operational level

The operational level is composed of the deployment or simulation of real scenarios under specific conditions (environment, vehicle, traffic). The main tasks of SaPPART at the operational level are:

- Definition of some generic operational scenarios representing some standard road environments and vehicles trajectories.
- Development of a generic sensitivity analysis method for the derivation of the required performance of the positioning terminal from the application level KPIs.
- Study and proposition of various test procedures to assess the service levels of the positioning terminals.

III. Role of Positioning in Road Transport

Positioning information plays an important role in road transport. The awareness of real time location of vehicles and people enables the effectiveness of transport services including quicker, cheaper, safer, more optimal operations, and a reduction in the emission of $CO2$. The awareness of the statistics of this information over a period of time enables the governments, service providers to make correct planning decision to meet future needs on road transport. Furthermore, it can also facilitate the emergence of new applications and services.

The introduction of positioning system in road transport is relatively new compared to the long tradition of the maritime and the civil aviation domains. The concept of navigation developed for the civil aviation purposes cannot be simply transposed to road applications. The aim of the Required Navigation Performance (RNP) is mainly focusing on the navigation capability that allows crews to fly aircraft along a precise path with the adequate accuracy and the ability to determine aircraft position with both accuracy and integrity.

A. Location-based transport services

Positioning information has already been used in many location-based transport services including

- Travel and traffic management services,
- Advanced driver assistance & vehicle safety services,

- Personal mobility services,
- Public transport management services,
- Commercial vehicle operation services,
- Emergency management services,
- Road user charging services.

Positioning information has been employed by some governments and local authority to understand the travel modes and behaviour of the citizens. Examples include UK National Travel Survey [4], Transport for London buses service performance data [5]. The statistics will further assist planning and investment on road transport services.

B. *Added value of accurate positioning*

The positioning information is mainly provided by GNSS receivers. The performance and cost of the receiver are the dominating factors to provide values added services including:

- Supporting new services for example cooperative driving in junctions,
- Improving the quality of current services for example punctuality of public transport operation,
- Supporting critical services for example value goods transport,
- Enhancing the integrity of data collection for decision makers,
- Improving the quality of life for example reducing passengers' waiting time through the use of real time location information for the prediction of arrival time.

The relationship of the accuracy and the services can be support is shown in Figure 3. It can be seen that the higher the accuracy, the more stringent services can be supported.

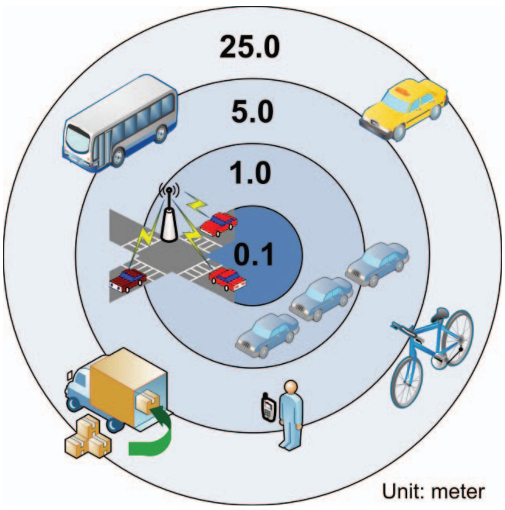

Fig. 3. Level of required accuracy in road transport [3]

C. *Challenging road applications*

There are many challenges in realisation of value-added services with location information and their providers including the identification of the future transport services and requirements, technical challenges and non-technical challenges.

There are many transport services that can be foreseen now, which decades ago were part of distant science fiction scenarios, such as e.g. driverless vehicles. However, there are also many transport services that cannot be foreseen now ones which are not considered as critical but will be in the future, for example the vehicle dynamics related comfortability. It is challenging to identify the future services based on the social evolution, culture variation and technology advancement. It is also challenging to derive the accuracy requirements of the associated future transport services requiring location information.

In the past, the availability of location information with GNSS was the primary challenge. There are many solutions including integration with dead-reckoning sensors, mobile network signals and map-matching. However, the challenges remain in some environments such as indoor/underground car park. Whereas the accuracy has improved with various techniques including vector tracking, internal filtering, and differential corrections. But there are still challenges related to for example the direct use of GNSS carrier phase measurements for road users. More challenging issue is the integrity (the trust the user can have in the positioning quantity delivered, discussed in more detail below) of location information in road transport. It is an enabler for all the current and future critical services in road transport and personal mobility. From providing the best option for a traveller perspective, the challenge is to have integrated information taking into account all surface transport modes including bus, train, tram, ferry, taxi, car-sharing and bicycle hiring etc. This requires co-operative surface transport operation enhanced by real-time location information and other techniques for example the smart electronic ticketing.

There are also non-technical challenges which many have direct impact on technical issues. For the political or economic reasons some of the GNSS owners have compulsory rules that their own system must be used. There are uncertainties if the benefits of the use of signals from multiple constellations can be fully exploited especially for critical services in surface transport section. There are also concerns on the privacy issue. The future legislation has many restrictions on the collection and use of location data. There are also concerns of the user security related issues. These issues may be converted to future technical challenges.

IV. CONCEPT FOR A POSITIONING TERMINAL

This section describes the concept of the positioning terminal used in SaPPART. First the positioning terminal's architecture and the variables describing the information exchanged between the terminal and the road transport application in question are discussed and then the most relevant performance features and metrics presented.

A. Architecture

One scientific focus of SaPPART is to analyze the different possible configurations and architectures of GNSS-based positioning terminals used in road transport applications. At present, GNSS alone cannot provide sufficient performance for all ITS applications, however due to its superior features it is the key technology in the positioning terminal. Augmentation of GNSS is needed to fulfill requirements for high position accuracy and precision set by some ITS applications, and to untangle the challenges of blockage and reflection of signals in urban areas.

The positioning terminal may embody means for augmenting GNSS. Prevailing method for such augmentation is the fusion of sensors or other radio positioning means, like cellular networks, and map-information. Sensors, e.g. magnetometers, odometers, inertial and optical sensors, provide direction and displacement measurements. When sensor measurement data are fused with GNSS data they may be used for improving the positioning terminal performance. The relative position information computed form sensor measurements might also be propagated and used for replacing GNSS for a short time.

Map-aiding, Satellite Based Augmentation Systems (SBAS) [8], differential networks (DGNSS) [10] and Assisted GNSS (A-GNSS) [7] via a Central Assistance Server (CAS), are widely used for GNSS augmentation. However, from the application's point of view the technologies used for forming the position solution are not interesting, but the performance of the terminal. Therefore, it has been agreed in SaPPART to define the positioning terminal as a black box, containing at least a GNSS receiver, as shown in Figure 4. Therefore, the work is concentrated on defining the most important performance features and metrics related to its outputs.

The outputs of the SaPPART positioning terminal are position, speed, time and protection level. Position is defined as the location of the terminal's antenna phase centre. Terminal's velocity relative to the ground is usually represented by speed, namely the norm of the three-axis velocity vector. Time denotes the timestamp of the instance to which the output corresponds to and protection levels are values related to integrity, which will be defined below. The positioning terminal may also output optional information for improved performance. Such information include Dilution of Precision (DOP) values, covariance matrices of estimation errors, satellites in view and information about the augmentation methods, like GNSS computation mode (DGNSS, SBAS) or sensors and other information used for position computation. However, the optional information is not taken into account in the performance evaluation discussed below.

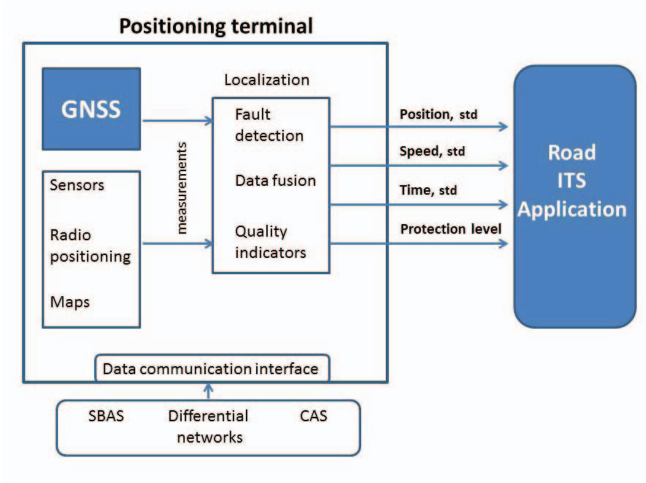

Fig. 4. Architecture of a positioning terminal used in SaPPART, figure based on [11].

B. Performance features and metrics

The four basic features describing GNSS performance are accuracy, integrity, availability and continuity [9]. Accuracy defines the trueness (trustworthiness; closeness of measurements of a quantity to that quantity's true value) and precision of the obtained output measurement. Integrity is a measure of trust that can be set on the positioning terminal's output, and includes also the ability of the system to warn the user when the output has a harmful error. Availability denotes the percentage of operating time, during which the positioning terminal provides a solution to the required level of accuracy and integrity. Continuity is a feature used by the aeronautics and defines a probability that the system will stop providing outputs with required quality due to e.g. failure of the navigation system [12]. However, continuity is not a relevant feature for ITS domain and is therefore replaced by another called timing performance composed of timestamp accuracy and output latency, update rate, jitter and Time To First Fix (TTFF).

Different metrics are used for characterizing the performance of the positioning terminal. The set of metrics consists of metrics for each combination of a performance feature with an output variable. For example, position error, in terms of accuracy, is represented with a set of three statistical values given by the 50th, 75th and 95th percentiles of the cumulative distribution of the position errors [6]. These metrics may be further specified to address a certain component of the position, e.g. horizontal or 3D. The use of metrics based on the cumulative distribution function (CDF) to represent the trueness (trustworthy) and precision, respectively, instead of the commonly used mean and standard deviation of the error distribution, is justified by the fact that the error distribution is not always arising from a well characterized statistical distribution (like e.g. Gaussian distribution).

It is also important to notice that when characterizing the positioning terminal performance based on the metrics, the inputs to the process are not always directly the outputs of the terminal, but rather the errors related to the outputs. That is, the inputs for the characterization based on the above defined terminal outputs are position error, speed error, protection levels and timestamp.

V. Towards standardisation

The previous sections have indicated that it is quite complex to measure GNSS-based positioning terminal performances. However, the ITS stakeholders need clear information on how such a Positioning terminal would perform in its intended operational environment and many of them expect some specified quantified classes of performances, with respect to the various features of terminal outputs, in order to guide their choice. Ideally, they should be defined in form of standards, given their general broad acceptance on the market.

Since 2012, mainly two standardisation organisations have been directly addressing these performance issues: CEN-CENELEC (TC5, WG1) and ETSI (TC SES, WG SCN). Their approaches are coordinated and complementary.

CEN-CENELEC addresses Position quantities performances and the relation between Position quantities performances and End-to-End service performances, only for ITS applications. ETSI addresses Position quantities performances, Positioning system architecture issues and Data exchange protocols issues for any terrestrial application.

As far as the test methods and facilities are concerned, CEN-CENELEC prepares standards (prEN 16803-1/3, [6]) based on field tests using test vehicles and reference positioning equipment whilst ETSI develops laboratory tests specifications (ETSI TS 103 246-1/5, [13]) using GNSS constellation simulators. Both approaches have their advantages and drawbacks and complement each other, depending on the context.

Definitions of the main concepts used in this standardisation activity have been agreed between the two groups, ensuring that way the consistency between the final standards.

These two suites of standards will provide a framework for evaluation of performances of GNSS-based positioning terminals for ITS. It is expected that this framework will pave the ways for certified terminals, speeding up its use in ITS.

VI. Conclusion

This paper has presented the framework of the SaPPART COST Action with a particular focus on the necessity to define a common understanding on the positioning quality assessment. The concept of positioning integrity defined first by the civil aviation community is becoming slowly accepted by the ITS community and will be integrated soon in most of the safety and liability relevant applications of the road domain. The definition of the requirements in positioning on the application side is not an easy task and needs a lot of effort and concertation to be expressed in a common language. In this sense the contribution of SaPPART will be appreciated by all groups of stakeholders and working groups of the standardisation bodies involved in ITS. There is still a long way to go to assess all type of applications under several conditions and to certify the positioning terminals for the defined levels of requirements. However, this initiative has proved the feasibility of the methodology which consists mainly in creating the "virtual link" between the positioning platform on one hand and the application module on the other hand.

Acknowledgment

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