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Contents

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Satellite Earth Stations and Systems (SES).

1 Scope

The present document addresses location systems combining telecommunication networks with Global Navigation Satellite System (GNSS) and other navigation technologies in order to deliver location based services.

The analysis contained in the present document is intended to highlight the growing use of complex location systems in order to deal with the expansion of location based applications in a mass market. The objective is thus to demonstrate both relevancy and achievability of standardising a high-level architecture for these systems, and the associated minimum performance.

In order to achieve this objective, the present document first provides a reminder of the types of applications which rely on location information provided by such systems in order to provide services. Secondly, it describes these location systems, in terms of key functions to be fulfilled (also called key features) and available enabling technologies at system components level (navigation sensors, hybridization techniques). It also focuses on the definition of operation environments applicable to such systems (depending on the type of application). Finally, preliminary location systems architecture, interfaces and performances are defined.

It is highlighted that the scope of this technical work specifically excludes standardisation of safety of life applications related to civil aviation, which are already addressed through, in particular, Radio Technical Commission for Aeronautics (RTCA) standards.

2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at http://docbox.etsi.org/Reference.

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2.1 Normative references

The following referenced documents are necessary for the application of the present document.

Not applicable.

2.2 Informative references

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ETSI TR 103 183 (V1.1.1): "Satellite Earth Stations and Systems (SES); Global Navigation Satellite Systems (GNSS) based applications and standardisation needs".

[i.2] RTCA DO-229D (2006-12): "Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment".

[i.3] OMA-TS-ULP-V2-0-20100816-C (2010-08): "User Plane Location Protocol".

[i.4] ETSI TS 122 071 (V9.0.0): "Digital cellular telecommunications system (Phase 2+); Universal Mobile Telecommunications System (UMTS); LTE; Location Services (LCS); Service description; Stage 1 (3GPP TS 22.071 version 9.0.0 Release 9)".

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

application central part: entity hosting the Location based application, that interacts with a **Location system** central facility in order to obtain **Location information** for one or more **mobile targets**

NOTE: The application central part can be located inside or outside the **Positioning terminal**.

location based application: application which is able to deliver a service to one or several users, built on the processing of the **Location information** related to one or several mobile targets

location information: information about the position and other related information of a positioning terminal

NOTE: It is the main output of a **Location system**. The information can be of several types: not only the terminal position itself, but also the reliability of the reported position, the authenticity of the reported position, the probability that the terminal is/was in a given pre-defined area, information related to the terminal motion (speed, acceleration, gyros, etc.), etc.

location system: infra-structure for reporting to a location based application the **Location information** of one or several positioning terminals, periodically or upon request

location system central facility: logical entity, inside a **Location system**, that manages the location information exchange protocol with the application central part, which is the location system external client

mobile target: physical entity whose position the location system builds the location information on, and to which the positioning terminal is attached

positioning terminal: logical entity, inside a **Location system**, that contains a GNSS receiver and possibly additional sensors, and is physically located with the mobile target

NOTE: It executes the measurements needed to determine its position, and implements part of the location determination functions. It embeds the group of sensors needed to execute these tasks. This group can include navigation sensors (GNSS, Inertial, Odometers, etc.), wireless network modems (terrestrial or satellite).

3.2 Symbols

For the purposes of the present document, the following symbols apply:

φ	Carrier phase
δAccel	Error on sensor acceleration (from INS)
δAtt	Error on sensor attitude (from INS)
δGyro	Error on sensor gyroscopes (from INS)
δPos	Error on sensor position (from INS)
δPos_{3D}	Uncertainty on sensor position (from GNSS)
δV	Error on sensor attitude (from INS)
δV_{3D}	Uncertainty on sensor speed (from GNSS)
d	Carrier Doppler
P_{GNSS}	Position estimate coming from GNSS sensor
P_{INS}	Position estimate coming from the INS
V_{GNSS}	Speed estimate coming from GNSS sensor
V_{INS}	Speed estimate coming from the INS

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

3GPP	3rd Generation Partnership Project
ADAS	Advanced Driver Assistance Systems
AL	Alarm Limit
BTS	Base station Transceiver System
DOA	Direction Of Arrival
ECEF	Earth Centred Earth Fixed
EDGE	Enhanced Data for GSM Evolution
EGNOS	European Geostationary Navigation Overlay System
EMI	Electro-Magnetic Interference
FDAF	Frequency Domain Adaptive Filtering
GCF	Global Certification Forum
GEO	Geostationary Earth Orbit
GIVE	Grid Ionospheric Vertical Error
GLONASS	Global Navigation Satellite System (Russian based system)
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile communications
HPE	Horizontal Positioning Error
HPL	Horizontal Protection Level
IMU	Inertial Measurement Unit
INS	Inertial Navigation Sensor
IRS	Inertial Reference System
ITS	Intelligent Transport Systems
LCS	LoCation Services
LEO	Low Earth Orbit
LOS	Line Of Sight
LTE	Long Term Evolution
MEMS	Micro Electro-Mechanical Systems
MEXSAT	Mexican Satellite System
MI	Mis-Integrity
MMI	Man-Machine Interface
MOPS	Minimum Operational Performance Specification
MP	Multipath
MPS	Minimum Performance Standard
MS	Mobile Station
NCO	Numerically Controlled Oscillator
NMR	Network Measurement Results
ODTS	Orbit Determination and Time Synchronisation
OMA	Open Mobile Alliance
OTDOA	Observed Time Difference Of Arrival
PAYD	Pay As You Drive
PE	Positioning Error
PL	Protection Level
PRS	Public Regulated Services
PVT	Position, Velocity and Time
QoS	Quality of Service
QZSS	Quasi-Zenith Satellite System
RAIM	Receiver Autonomous Integrity Monitoring
RF	Radio Frequency
RMS	Root Mean Square
RTCA	Radio Technical Commission for Aeronautics
RTK	Real Time Kinematic
SBAS	Satellite Based Augmentation System
SCN	Satellite Communications and Navigation (Working Group of TC-SES)
SMLC	Serving Mobile Location Center
SUPL	Secure User Plane for Location

SV	Satellite Vehicle
TBC	To Be Confirmed
TBD	To Be Defined
TC-SES	Technical Committee Satellite Earth Stations and Systems
TTA	Time To Alarm
TTFF	Time To First Fix
UDRE	User Differential Range Error
UERE	User Equivalent Range Error
UHF	Ultra-High Frequency
UMTS	Universal Mobile Telecommunications System
VPL	Vertical Protection Level
WAAS	Wide Area Augmentation System
WI-FI	Wireless Fidelity

4 Location based applications needs

A thorough inventory of the location based applications is done in TR 103 183 [i.1]. This inventory is used as a reference in the present document. The present clause only acts as a reminder of the conclusion of this inventory, presented as a classification of these applications.

It is indeed possible to organize applications facing similar needs in a reduced number of classes:

a) Location Based Charging:

- The objective is to charge a user based on its reported position. The main requirements are:
  - **Reliability of check point crossing detection:** there is a risk that user reported position triggers a charging event whereas it is actually in a position free of charge.
    This risk is generally needed to be very low.
  - **The service availability:** the percentage of cases when user actual position has to trigger charging event, but system is not properly informed. The service unavailability can be due either to an erroneous reported position, or the unavailability of the location information itself.
    This service unavailability is generally needed to be low.

NOTE 1: This type of location-related requirement is needed for road user charging (road), on-street parking fee pricing (road), waterways and harbours charging (maritime/multimodal), home zone billing, regulated fleets in urban areas, etc.

b) "Pay As You Drive" (PAYD) charging:

- The objective is to charge a user based on the travelled distance (mainly applicable for pay-per-use insurance). The challenge is quite similar to the previous group, except that useful information is rather the travelled distance than the position itself.
- The main drivers are:
  - the representativity of the computed distance; or
  - the representativity of the followed trajectory;

  in order to globally optimise the fee collection.

NOTE 2: This type of location-related requirement is needed for pay per use insurance (road), car rental pricing (road), taxi service pricing (road), freight tolling (road), car pooling (road), pay as you pollute (road), energy charging (train).

c) Cooperative basic geo-localization (including fleet and asset management):

- The objective is to recover the position of one or several assets or vehicle, remotely or otherwise. The main drivers are generally:
    - **The reported position accuracy:** as far as fleet management or personal navigation is concerned, the main target is explicitly to obtain an accurate position estimate.
      The required accuracy highly depends on the application: tens of meters for personal road navigation and vehicle fleet management, meters for pedestrian personal navigation and city sightseeing.
    - **The service availability:** position availability might not be as driving as for other application (see location based charging applications), but it is a clear challenge in the considered applications: car positioning in urban area (including high masking or shadowing, tunnel, important multipath) clearly suffers from degraded availability.

NOTE 3: This type of location-related requirement is needed for fleet/asset/resource management, personal navigation (pedestrian, road, multi-modal), traffic travel info, city sightseeing, etc.

d) Non-cooperative geo-localization (possibly applied to fleets):

- Asset positioning might be required when asset is non-cooperative. In other words, compared to the regular "cooperative basic geo-localization", a new driver is reported: the **service reliability**.
- In other words, this new requirement is important any time the terminal is placed in a "hostile" environment, and that the confidence in the reported position is maximized.

NOTE 4: This type of location-related requirement is needed for some kind of fleet management (car rental), car recovery after theft (road), city logistics (road).

e) Reliable geo-localization (including dangerous, precious and/or sensitive cargos):

- The objective is to obtain a reliable position estimate for any application where position is a key driver for security or safety (of cargo, travellers).
- The main driver here is the **confidence level associated to the applicative figure of merit**. This figure of merit can be:
    - the reported position;
    - application event: billing event, trajectory.
- In other words, for such applications it becomes paramount to be informed of the probability that reported information is inaccurate.
- Of course, **reported position accuracy** and **service availability** are important drivers, which might however depend on the specific applications.
- The border between "non-cooperative" and "reliable" geo-localization is thin. To that point, they are however considered separately:
    - Non-cooperative geo-localization only targets position uncertainty caused by position spoofing (i.e. wanted). In other words, any position uncertainty due unwanted origins (GNSS signal, interference, other) are not covered: they are deemed naturally bounded, and the application required accuracy is compatible with this bound.
    - Reliable geo-localization however covers all sources of position uncertainty, in order to bring confidence not only in the position authenticity, but position accuracy.

NOTE 5: This type of location-related requirement is needed for livestock transport tracking and tracing survey, dangerous and hazardous cargoes tracking and tracing survey, special (high value, sensitive, dual) goods traffic tracking, perishable goods / food tracking and tracing.

f) **(Reliable) Vehicle movement sensing:**

- Some application aim at collecting, in addition to the terminal position, additional information related to its movement: speed, acceleration, heading, gyration, etc.:
    - The main driver is of course the **movement caption accuracy**. The objective might to measure vehicle speed for law enforcement of eco-driving advice.
    - As previously mentioned, a **confidence level** associated to the reported parameter might also be needed.

NOTE 6: This type of location-related requirement is needed for:

- Liability critical applications: legal speed enforcement (road), accident reconstruction (road), vehicle control assistance (ADAS) + collision warning (road), cold movement detector (train), traffic management systems (train).
- Non-liability critical applications: eco-driving and carbon emissions foot- printing (road), traffic congestion reporting (road).

5 Location systems

In the previous clause, a set of location systems functional needs has been established.

Clause 5 now proposes a description of the location systems allowing to achieve the identified function.

The first step is to provide a generic context in which location systems are likely to step in. Secondly, we intend to define a high level technical specification applicable to location systems, in order to define location systems **key features** allowing to fulfil the required functions. Then, a review of the enabling technologies allowing to support these key features is executed. Finally, the operational environments in which the location systems are expected to perform are also reviewed.

Consequently, we first propose to review generic architecture of a location system, and then list the location system key features that need to be addressed in order to answer to the application level needs.

5.1 Generic context

In order to better capture the purpose of location systems, this clause provides a description of the generic context in which Location systems are needed. Figure 1 thus shows how such systems could be integrated to other systems and external service providers in order support location based service.

The considered scenario envisions a location based application, which delivers to an external entity (unknown, out of the present work) a service based on the location of a number of mobile targets. The central part of this application thus addresses a request to a location system.

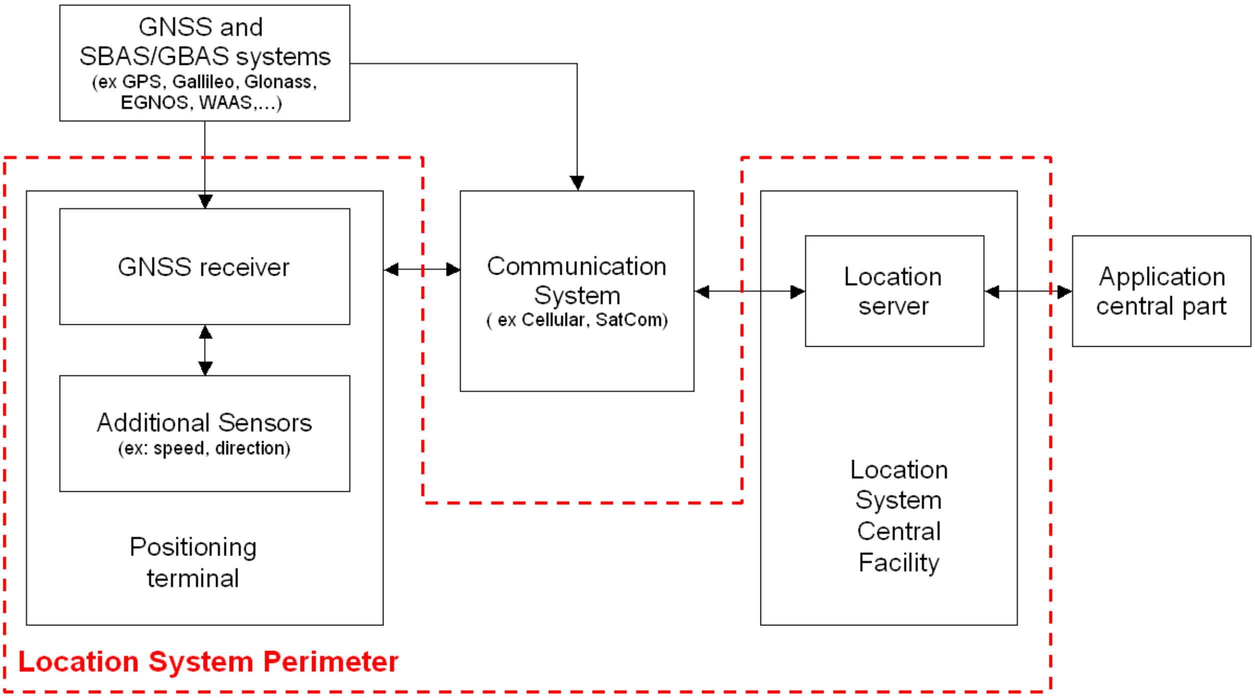


Figure 1: Generic context for location systems use

In the situation described above:

- The GNSS receiver inside the positioning terminal offers the ability to track the signals received from the system(s) constellation(s), and thus provide measurements or position estimate.
- Additional sensors are also available inside the terminal, in order to provide complementary location-related data.
- Both GNSS receiver and sensor are integrated in a single device, identified as a positioning terminal.
- Whenever a location request, initiated by the application central part (external location system client), is processed and transmitted by the Location system central part to the positioning terminal, it triggers measurements at terminal level, resulting in location data (either terminal position or specific measurement).
- This data sent back to the location system central part for further processing, consolidation and formatting.
- Furthermore, an interface between the ground infrastructure of the GNSS or SBAS systems and the location system central part can also be considered, through a dedicated communication mean. This interface allows to convey GNSS navigation data as uplinked towards the spacecrafts, or augmentation data. The communication link used is possibly different from the one connecting the positioning terminals to the central part. However, in figure 1, the same "communication system" box gathers both means of communications.

The generic architecture given above is a high level description of location systems use. It provides the generic framework, which adapts to most of the conceivable use cases (see example in clause 4).

5.1.1 Architecture example from existing systems

Historically, it is considered that GNSS is the primary means of location. But it has to be complemented by other location means to satisfy the location service availability requested by the some application and users. A very good example is inside the 3GPP framework. In this case, the Location system is made of the Mobile Station (MS), equivalent to the positioning terminal, the SMLC (Serving Mobile Location Center), equivalent to the Central facility, and it includes a communication function that relies on the mobile communication network. This is fully described in TS 122 071 [i.4].

The following is intended to show how such location systems operate. It also illustrates how the positioning terminal is embedded in such architecture.

GNSS systems infrastructure are basically composed of the following segments:

- The space segment, composed of the satellites constellation that disseminate the signal- in- space to the user segment.
- The ground segment, including the ground control segment devoted to the control of the satellites constellation, and the ground mission segment devoted to the preparation of all the data to be included within the signal -in -space.
- The user segment, including any GNSS receiver that uses the GNSS signal- in- space to determine its position. Other sensors may exist in the terminal to enhance the positioning performance in difficult environments.

The main GNSS today operating or under development are GPS, Galileo, Glonass, modernized GPS, and Compass.

In addition to GNSS, Satellite Based Augmentation System also allows to support wide-area or regional augmentation through the use of additional satellite-broadcast messages. Such systems are commonly composed of multiple ground stations, located at accurately-surveyed points. The ground stations take measurements of one or more of the GNSS satellites, the satellite signals, or other environmental factors which may impact the signal received by the users. Using these measurements, information messages are created and sent to one or more satellites for broadcast to the end users.

Galileo studies also considered local elements that are NOT part of the GNSS infrastructure, but bring further location data to the GNSS receiver to allow them to locate themselves in certain difficult conditions. These local elements may be for example, mobile communication networks elements (GSM Base station Transceiver System (BTS), UMTS "NodeB"), that provide RF signal used by positioning terminals, or dedicated equipment such as pseudolites.

An interface appears between the GNSS ground mission segment, and the mobile communication network location infrastructure, to convey the GNSS navigation data that may be acquired from the signal- in- space using a GNSS receiver, but that may also be disseminated by the GNSS ground mission segment using a terrestrial communication link.

The following figures summarize the location provisionning systems, introducing also the concept of positioning (or location) terminal, which embeds a GNSS receiver, and additional location sensors.

The exchange of information are sequentially numbered on the arrows between the entities. The proposed example corresponds to the case where the location request is initiated by an application running on an external network (network initiated case).

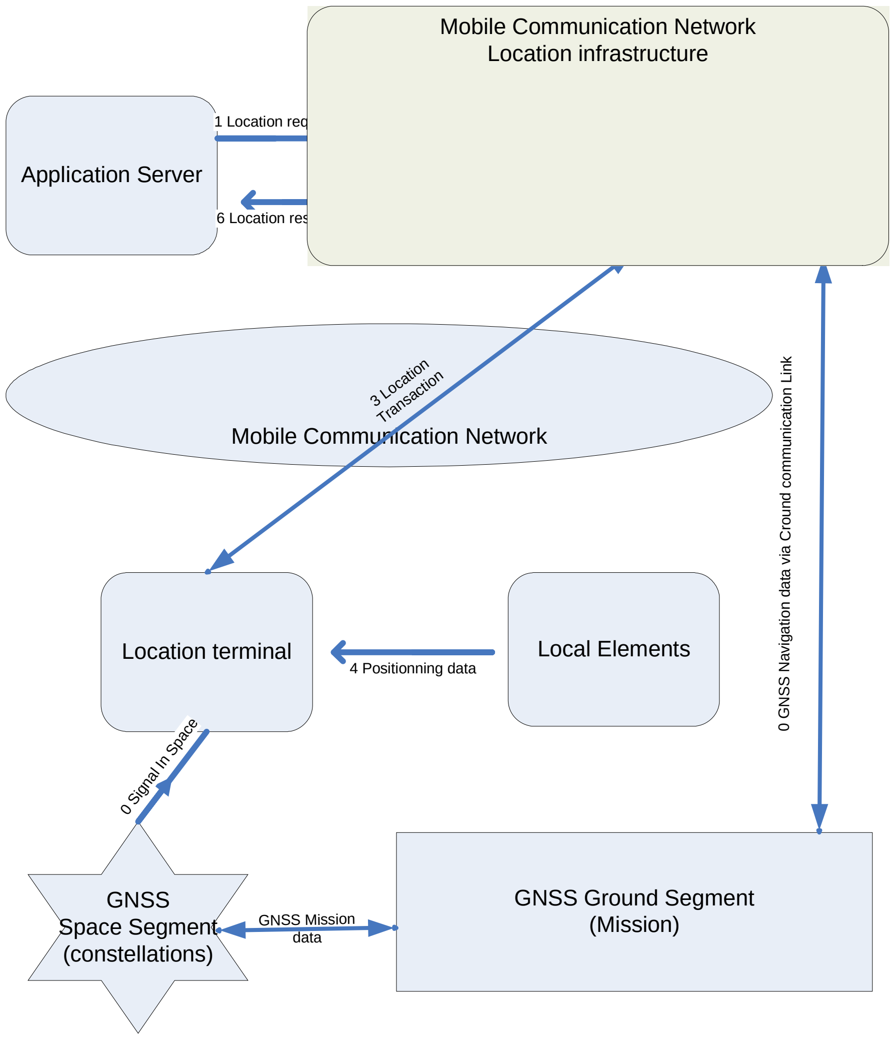


Figure 2: Example of location system in the 3GPP context

Mobile communication network location infrastructure elements are fully defined in the 3GPP standards dedicated to location, and also in Open Mobile Alliance (OMA) standards dedicated to location using the Secure User Plane for Location (SUPL) protocol. Functionally speaking, location servers in both domains are equivalent.

For more information concerning the functions borne by the mobile communication network location infrastructure elements, please refer to TS 122 071 [i.4].

5.2 Location systems key features

Based on the inventory of location based applications, it is now proposed to derive the identified key functions into location system technical specification. "Technical specification" should be understood here as follows: functions previously listed are expressed in terms of application user requirements. Derivation of associated location system technical specification consists in translating them into technical requirements, exploitable at location system level. The main technical requirements derivated are the key features presented in this clause.

As far as location needs are concerned, a list has been established in clause 4. Table 1 summarizes these needs, and proposes a list of technical key features allowing to fulfil these needs and a mapping to these needs towards the location system key features.

Table 1: Application needs and location systems key features

Mapping: Application needs vs Key features		Location system key features: position horizontal accuracy	Position authentication	Position availability	Position integrity	Interference rejection
Application needs	Reliability of the detection of check point crossing (location based charging)	X	X			X
	The billing service unavailability (location based charging)	X		X		
	Representativity of the computed distance (PAYD)	X	X			X
	Representativity of the reported trajectory (PAYD)	X	X			X
	The reported position accuracy (cooperative and non-cooperative geo-localization, reliable geo-localization)	X				
	The location service availability (cooperative and non-cooperative geo-localization, reliable geo-localization)			X		
	Service reliability (non-cooperative geo-localization)		X		X	X
	Confidence level associated to the applicative figure of merit (reliable geo-localization)	X			X	
	Movement caption accuracy (vehicle movement sensing)	X				X
	Confidence level associated to the reported parameter (reliable vehicle movement sensing)	X			X	

In order to further describe the proposed key features, and support the above mapping, the following clauses describe these features.

5.2.1 Position horizontal accuracy

5.2.1.1 Feature description

This is the most common location system performance, and is quite explicit: accuracy is measured as the error between the reported position and the actual position of the sensor. Horizontal accuracy is the derived 2D position error.

NOTE: Vertical accuracy could also be taken on-board the technical framework, but none of the considered applications explicitly require for position vertical accuracy.

5.2.1.2 Feature metric

It is usually expressed in meters, as the Root Mean Square (RMS) of the Horizontal Positioning Error (HPE). The horizontal positioning error is computed as the distance between the 2D reported position and the 2D true position (i.e. projected on the horizontal plane).

5.2.1.3 Example of implementation

The development of location sensor able to provide accurate position estimate is the basic challenge taken by any GNSS receiver manufacturer, with comparable performances for each of them.

The techniques behind these implementations being very similar among them (at least the basic ones) and well documented in many GNSS bibliographic sources, no details are provided here.

5.2.2 Position authentication

5.2.2.1 Feature description

As exposed previously, a significant number of applications are sensitive to the reliability of the reported/computed position: "Can I trust the position reported by such asset?".

At the location system level, this is translated into a need for position authentication. The concept of authentication is proposed to be analysed in this clause.

GNSS service vulnerabilities:

Geo-localization using GNSS signals relies on the processing of the input Radio Frequency (RF) signals coming the satellites system. Among all available systems, the signal most often offered are unencrypted signals (GPS L1C/A, GPS L1C, GALILEO Open Service, GLONASS, etc.). These signals are clearly GNSS system weakpoint, since it is theoretically and practically very "easy" to spoof a receiver with a RF signal generator, replaying signals recorded at another location: if appropriately modified, software receivers can be converted into spoofers by reverting the receiving chain, adding some offsets to each satellite signal and irradiating a modified version of the received signal in the air.

The objective is clear: in a location based charging application, a non-cooperative user or attacking third party can:

- Record the GNSS signals when using a toll free road (red path below).
- While using the paying road (blue path below), replay the recorded RF signals, and thus report to the monitoring system a spoofed trajectory, corresponding to a toll free use case.

Figure 3: Example of spoofed trajectory versus true trajectory

The motivation is clear: avoid billing (money), law enforcement (prisoner monitoring), spoof a positioning unit to hijack a monitored cargo or asset.

Authentication solutions:

Three main threads are explored to implement authentication:

1) Technological thread:

- It mostly concerns the possibility to hybridize regular GNSS receivers with additional sensors, into a positioning terminal. The key methods identified relied on hybridisation again following two axes:
    - Hybridisation with low cost inertial, magnetic sensors, odometers.
    - Hybridisation with network positioning (namely cell-id and Network Measurement Results (NMR)).

NOTE: Such a function can be fully implemented on-board the device, which turns into a positioning terminal rather that a standalone GNSS receiver.

2) Profiling thread:

- This centralises all the possible improvement brought to the authentication performance through the use of the user's dynamic model. It can be derived either from known mechanical characteristics, or from known use cases.
- Such function is usually implemented at location system infrastructure level, to which the terminal is connected through the communication network, since access to user data base is needed.

3) Encrypted context thread:

- Authentication can also be achieved exploiting military/regulated services encryption feature, but on a regular (i.e. non-military) location terminal. The basic principle is:
    - GNSS receiver can sample a short period of RF signal.
    - Transmit it to a location center imbedding the capability to correlate with the military/regulated spreading codes.

  and therefore ensure that the RF signal fed into the GNSS receiver is indeed collected from the regular constellation.

5.2.2.2 Feature metric

The authentication performance is proposed to be measured as the fraud detection performance.

In other words, two figures of merit are used:

- the mis-detection performance;
- the false-alarm rate.

NOTE: The performance depends on the nature of the threat. This is addressed in clause 6.3.2 Authentication.

5.2.2.3 Example of implementation

Using the above techniques, simulations have been executed. The scenario is:

- the mobile is equipped with GNSS receiver and an Intertial Navigation Sensor (INS);
- it follows a given "true" trajectory;
- it is spoofed with a GPS signal previously recorded, while following another trajectory;
- the discriminating criteria used to detect spoofing (and build authentication) are the heading and the heading change rate information.

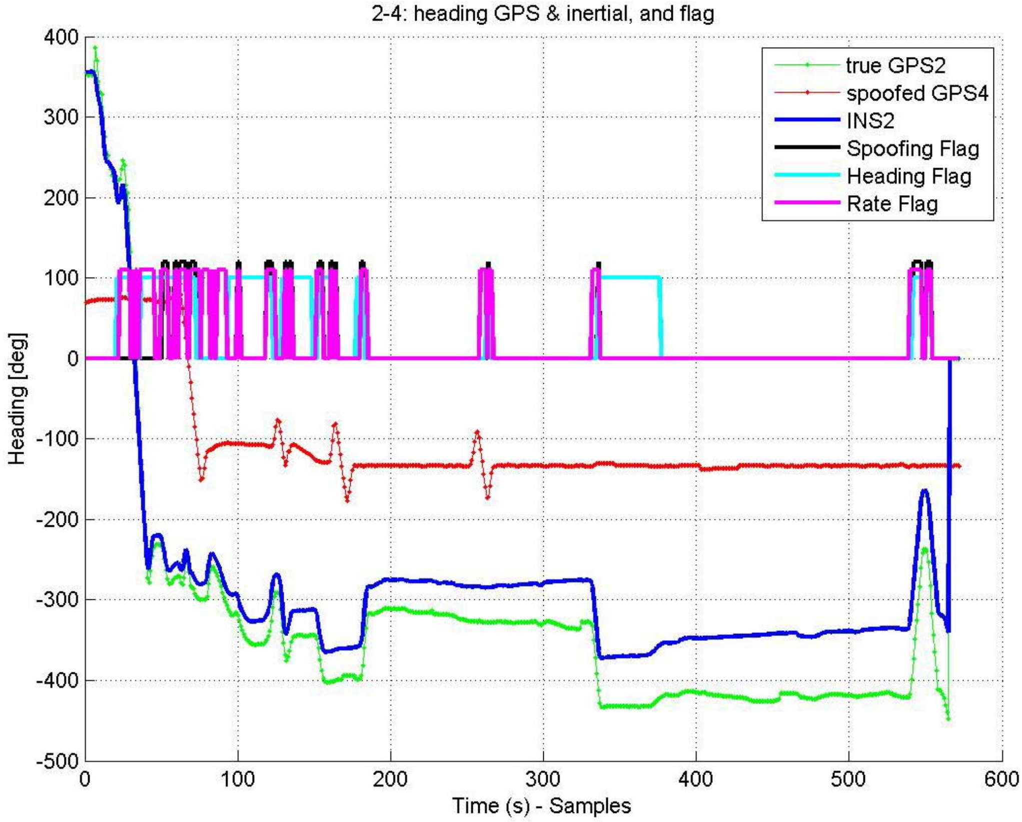


Figure 4: Authentication means description

We can clearly see that:

- heading recovered from un-spoofed GPS location (green curve) and INS (dark blue curve) are consistent;
- heading computed from the spoofed GPS location (red curve) is totally inconsistent;
- based on the comparison of this information, flags can be raised any time the consistency of information coming from the various sensors drops below a certain level (light blue curve for heading info, purple curve for heading change rate information, and dark curve for the spoofing flag obtained via consolidation of the two previous ones).

Similar concept can be applied to communication sensors data, which also provide a location estimate (even if it is a coarse one):

- along a given trajectory, terminal connects successively to different Base Station Transceiver Systems (BTS);
- each BTS as a known position and coverage area;
- a spoofing attempt can lead to inconsistent information between reported GNSS position and serving cell identification;
- the longer the trip is, the more likely is the spoofing detection.

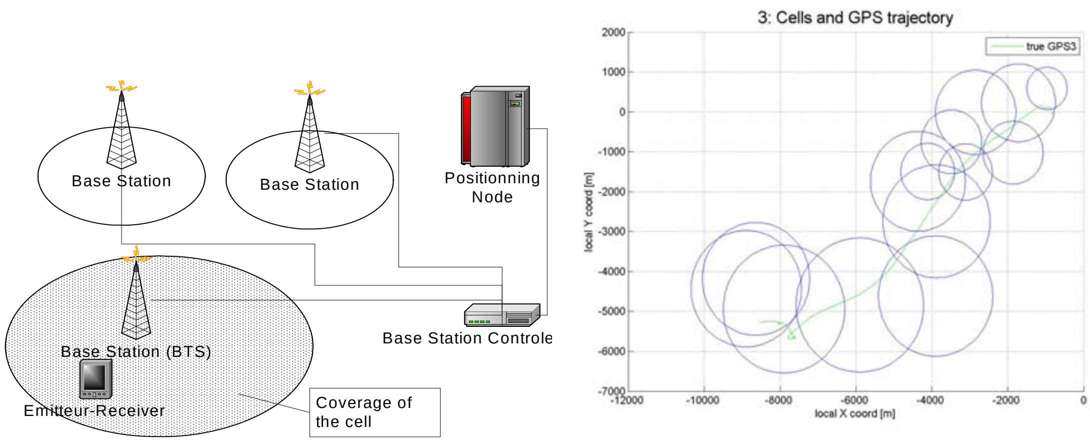


Figure 5: Authentication using serving cell IDs along a terminal trajectory

5.2.3 Position availability

5.2.3.1 Feature description

Position availability is a key driver, in particular for multi-modal applications (outdoor to indoor). It represents the availability rate of the position information at location system output.

5.2.3.2 Feature metric

It is expressed an availability rate, usually expressed as a percentage.

5.2.3.3 Example of implementation

For liability-critical applications, availability performance is inter-correlated with integrity. This is developed in the next clause.

5.2.4 Position integrity

5.2.4.1 Feature description

A number of applications relies on the use of a reliable user position, which in particular implies the capability to have a confidence level associated to the reported position.

This is commonly translated as position integrity into location systems reference frame as position integrity.

The concept of integrity is inherited from civil aviation, which is historically the main safety critical application eager to use the GNSS positioning systems.

The main core performance indicator of such system is the navigation system error defined as the 95^{th} percentile of the positioning error. Such indicator was however not enough for application such as civil aviation. Indeed, when used for plane approach or landing, an error in a position may have direct implication in the safety of life of the crew and passengers. Therefore an estimation of the position at 95 % was clearly not adapted to such an application.

The use of GNSS system by civil aviation implied the definition of different integrity related performance indicators. Among others, two major ones are:

- The confidence level of the position provided by the GNSS system is required to be better than 1 to 2 x 10^{-7} in 150 s in order to be compatible to safety of life application.
- In case the position is not correct, the system is able to provide warning to users within the applicable time to alarm of 6 s.

At the technical level, this was implemented through the following concept:

- The Positioning Error (PE) is the distance between the computed position using GNSS, and the actual true position.
- The concept of Protection Level (PL) is introduced. It can be determined by the GNSS, and is intended to provide an upper bound of the PE.
- The case when PL < PE (intended to be as low as possible, especially for civil aviation) is assimilated to Mis-Integrity (MI). In that case the system is expected to warn the user within a given time lap, called Time To Alarm (TTA).
- Finally, the probability that PL < PE and that the system does not warn the user within the TTA (i.e. the user exploits a bad PL without knowing it) is called the integrity risk.

Note that for what concerns the scope of the present document, all positions are horizontal position, so that PE and PL becomes HPE and Horizontal Protection Level (HPL).

5.2.4.2 Feature metric

The metrics for integrity functions and integrity-related needs from application point of view are:

- Horizontal Protection Level (HPL), expressed in meters.
- Time To Alarm (TTA), expressed in seconds.
- Alarm Limit (AL), expressed in meters.
- Availability figure, expressed in percentage of time when HPL < AL.

5.2.4.3 Example of implementation

There are different algorithms designed for protection level computation depending of what is available at user level. In the frame of SBAS development such as Wide Area Augmentation System (WAAS) and European Geostationary Navigation Overlay System (EGNOS), Vertical Protection Level (VPL) and HPL computation have been standardized in RTCA DO-229D [i.2]. For standalone user, different techniques have been developed in the frame of the Receiver Autonomous Integrity Monitoring (RAIM) concept:

- The integrity of the navigation solution relies on the confidence level provided to the user on the different error budget potentially impacting the user measurements.
- Those contributors can be differentiated in two categories: local effects and system effects:
  - **System effects including Orbit Determination and Time Synchronization (ODTS) correction error and ionospheres error**, are monitored by SBAS system in real time. Accurate indicators (User Differential Range Error (UDRE) and Grid Ionospheric Vertical Error (GIVE)) are provided in real time to the users. If the system is not able to provide accurate enough indicators it will issue an alarm on the parameter at fault.
  - **Local effect such as troposphere, multipath, inference** are not monitored by the system. The solution is to standardize models enabling to correct and over-bound the residual error with the required confidence level. The definition of such a model has been made possible thanks to the homogeneity of the scenarios encountered in the civil aviation application. For instance, for what regards multipath, the main contributor is coming from the disturbance generated by the local environment of the antenna that is the aircraft itself.

The aviation integrity concept has been extensively validated for civil aviation users. However its direct application to terrestrial applications, such as the ones targeted in the present document, and using stand-alone GNSS receivers has already proven itself unsuccessful.

Thus, figure 6 presents the results obtained in an **urban measurement campaign**.

On the left side, the HPL is being calculated with the Minimum Operational Performance Specification (MOPS). It can be seen that many non-integrity situations can be observed.

On the right side, the K_{sigma} parameter from MOPS has been increased so that MI = 0 %. In that case integrity is indeed preserved, however the alert limits are getting huge (several hundred of meters).

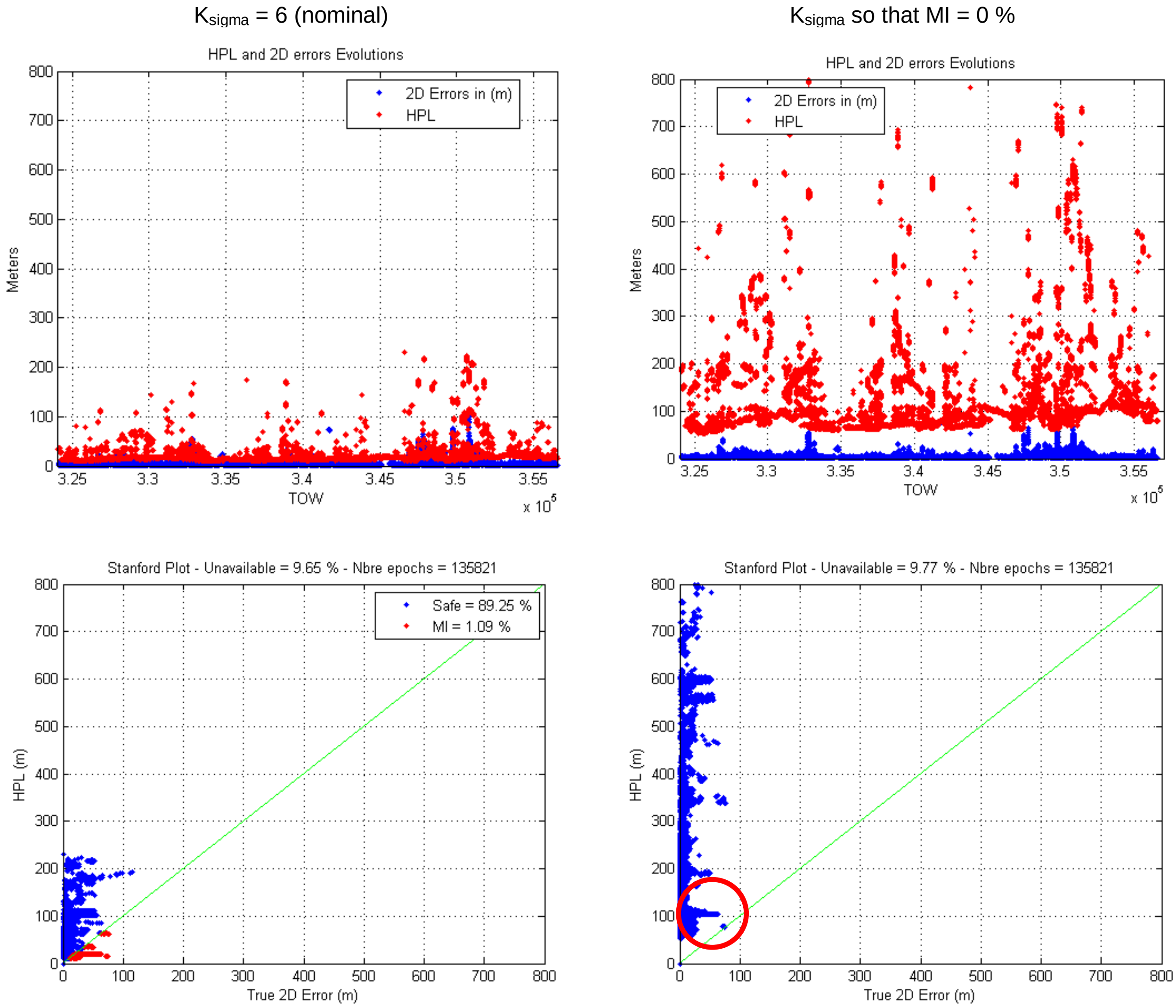


Figure 6: Application of civil aviation algorithms to urban application

Thus, using the MOPS algorithm, in order to keep an integer positioning (i.e. position is known with a trusted confidence level), HPL needs to be increased up to 800 m. However, as far as typical terrestrial applications are concerned, such "relaxed" safe envelop is useless. For instance, a geo-fencing application may require:

- 95^{th} percentile of HPL below 50 m (i.e. 95 % of the time);
- 99^{th} percentile of HPL below 100 m;
- $99{,}99^{th}$ percentile of HPL below 200 m;
- An MI rate below 0,001 %.

Indeed, for such requirement sets, the billing is based on the following rules:

- If the HPL is below 50 m, the lower billing rate within 50 m around the user position;
- If the HPL is below 100 m, the lower billing rate within 100 m around the user position;
- If the HPL is below 200 m, the lower billing rate within 200 m around the user position;
- Otherwise no billing is performed.

An increase of the HPL will then reduce the MI but will also reduce the provision of service capacity. In figure 7, the three values of HPL for the same reported user position give a billing of respectively 200 €, 50 € and 10 €.

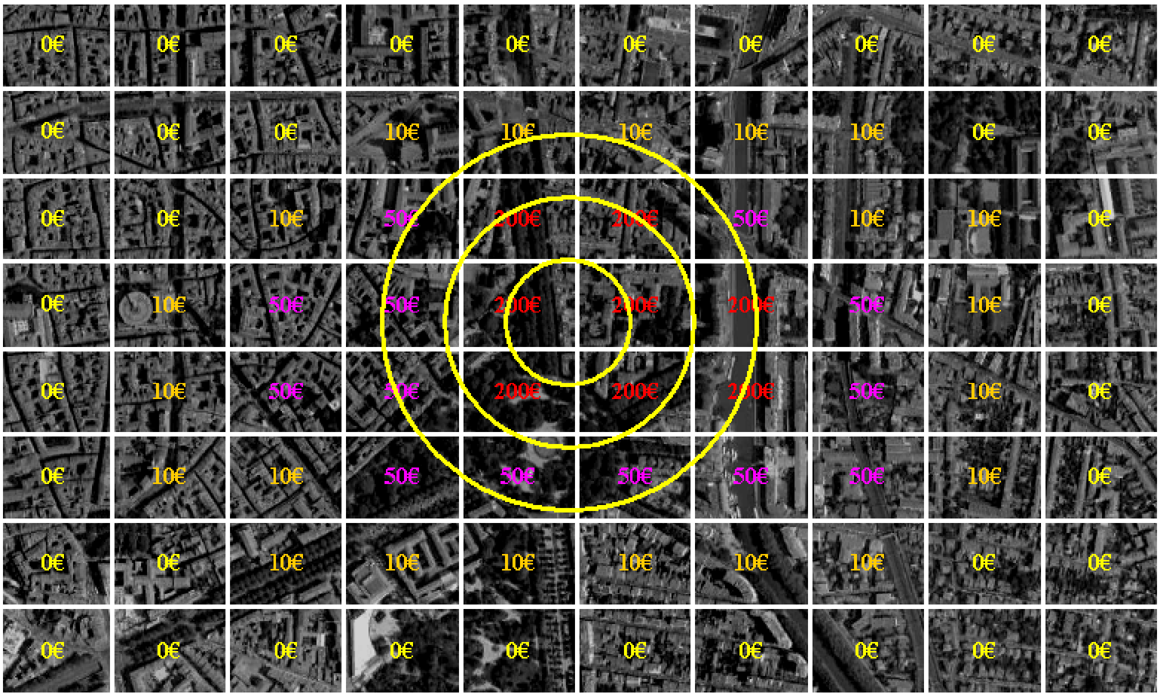


Figure 7: Integrity / Service provision trade-off

For a significant number of applications, the position needs to be reported with a given confidence level. This is usually translated into location system reference frame as positioning integrity.

Observations on availability:

Some applications might introduce the concept of Alert Limit (AL). This parameter is usually the maximum HPL allowed in the frame of the targeted mission. Whenever the HPL is above the AL, system is said to be non- available, i.e. positioning information cannot be used in the frame of the mission.

Consequently, availability figure described in the previous clause can be understood in two ways:

- For non-liability critical application, it is basically the percentage of time when location information is available.
- For application requiring a confidence level on the location information, availability figure depends on different factors:
  - 1st, as for non-liability critical application, the percentage of time when location information is available;
  - 2nd, the percentage of time when HPL is indeed computed and available at user level;
  - 3rd and last, the percentage of time when HPL > AL (with or without loss of integrity).

We therefore understand that availability and integrity are linked: an "artificial" decrease of HPL can improve the availability (3rd component above), but would be detrimental to location integrity (higher MI). On the contrary, increasing HPL allows the mitigate the integrity risk, but location information will have a limited use for some mission (function of required AL).

This is illustrated in the following graphs in figure 8.

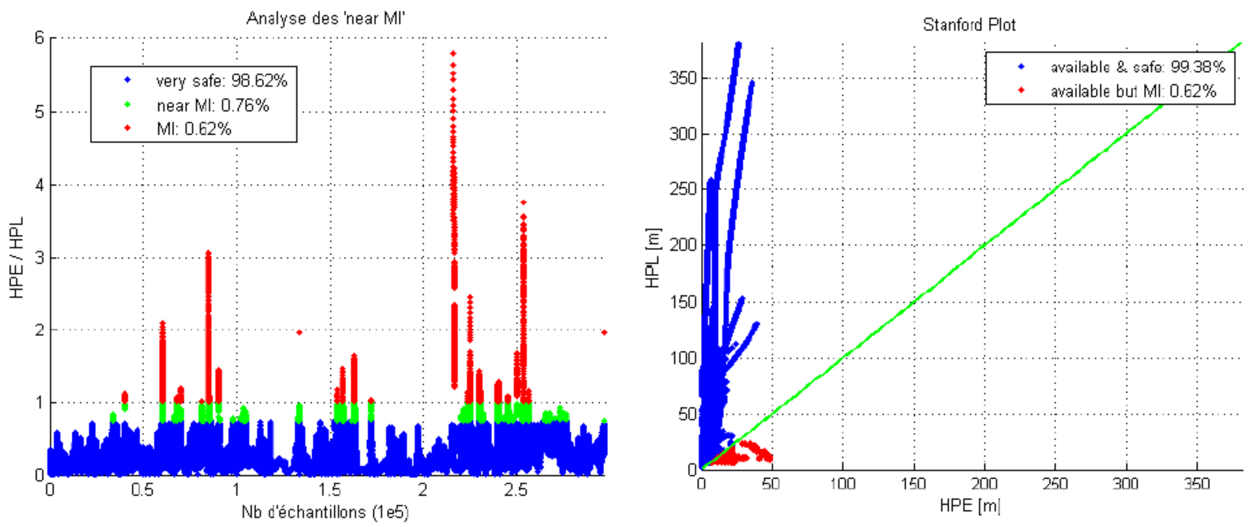


Figure 8: HPL versus HPE - link with application availability

5.2.5 Interference mitigation

5.2.5.1 Feature description

The specificity of most of the considered transport applications is the combination of challenging requirements and operational environment. As previously exposed, the environment conditions, in particular Multipath and interference, are among the most significant sources of positioning error.

Based on this statement, the possibility to efficiently mitigate for these contribution is undoubtedly a key feature expected on a location systems.

NOTE: "Interference" is understood as any RF signal perturbating the terminal measurement. It therefore embeds intentional and unintentional jamming, and multipath. Mitigation also addresses the characterization of the jamming and multipath sources. Characterization tackles parameters such as **frequency, power, Direction Of Arrival (DOA), delays (for multipath), and finally impact on terminal measurement.**

5.2.5.2 Feature metric

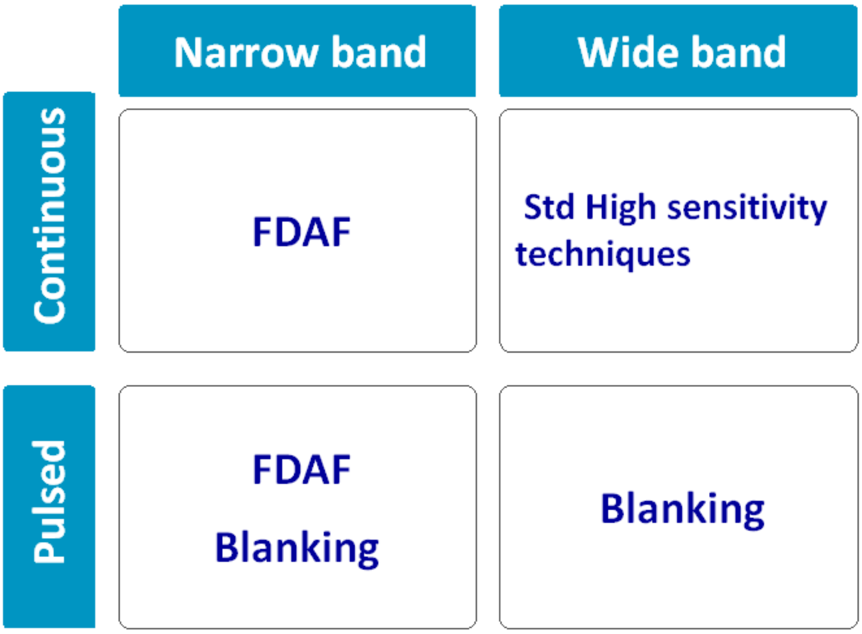
Metrics to be used for the interference mitigation features can be of many different types:

- Tolerable input RF power (at antenna port).
- Interference source isolation capability (in terms of direction of arrival).
- Tolerable multipath power.

These metrics will anyway be refined once the features themselves are identified and specified.

5.2.5.3 Example of implementation

Mitigation addresses ways to reduce the impact of interference on the position determination. Figure 9 illustrates the most common means today available to reduce this impact.



NOTE: FDAF stands for Frequency Domain Adaptative Filtering. It is a pulsed-interference mitigation technique which is an extension of the regular pulse blanking technique. Indeed, it uses an advanced filtering module to selectively remove the jammed frequency band instead of zeroing the whole signal.

Figure 9: Interference mitigation considered means

5.2.6 Additional key features

The list of key features addressed in the present document is limited to the above set. However, it does not mean that any additional key feature is irrelevant to location system. The rationale behind this limited scope is derived from the objective of the present document, which is to demonstrate the relevancy of the proposed standardization work.

In order to make it clear, the following list of additional key features which could possibly fall under the scope of the standardization task is proposed:

- Time to first fix (TTFF): time needed by a positioning terminal from power ON to the availability of a first position estimate compliant with the accuracy requested at service level.
- Vertical accuracy: this feature is the position accuracy projected on the vertical axis.

5.3 Mapping of application classes to features

Table 2 provides a mapping between:

- on one hand, the application classes previously defined;
- on the other hand, the key featured addressed in this clause.

This allows to understand how these features support the applications we consider.

NOTE: The present mapping is also included in TR 103 183 [i.1], but is repeated here to ease the understanding of the proposed analysis.

Table 2: Location applications versus key features

Application	Domain	Application class	Position accuracy	Position availability	Position integrity			Position authentication		Interference mitigation
					AL	TTA	Mis-Integrity	Mis-detection	False-Alarm	
Safe train positioning - high density	Train	Reliable geo-localization	20 m along track	99,9 %	50 m	6 s	2×10^{-7}/150 s			TBD
Safe train positioning - medium/low density	Train	Reliable geo-localization	50 m along track	99,5 %	100 m	6 s	2×10^{-7}/150 s			TBD
Level crossing, train length monitor	Train	Reliable geo-localization	100 m	99,5 %	150 m	6 s	1×10^{-7}/hour			TBD
Road charging	Road	Location based charging		50,0 %	20 m to 50 m	15 s	1×10^{-5}/s	< 0,1 % (TBC)	< 0,01 % (TBC)	TBD
Road charging - urban	Road	Location based Charging		90,0 %	20 m to 50 m	15 s	1×10^{-5}/s	< 0,1 % (TBC)	< 0,01 % (TBC)	TBD
Waterways charging	Maritime	Location based charging		90,0 %	20 m	15 s	1×10^{-5}/s	< 0,1 % (TBC)	< 0,01 % (TBC)	TBD
Pay per use insurance	Road	PAYD		99,9 %	20 m to 50 m	15 s	1×10^{-5}/s	< 0,1 % (TBC)	< 0,01 % (TBC)	TBD
Pay as you pollute	Road	PAYD						< 0,1 % (TBC)	< 0,01 % (TBC)	TBD
Car rental pricing	Road	PAYD						< 0,1 % TBC)	< 0,01 % (TBC)	TBD
Fleet management city logistics	Road	Non-cooperative geo-localization	10 m (95 %)	95 %				< 0,1 % (TBC)	< 0,01 % (TBC)	TBD
Recovery after theft	Road	Non-cooperative geo-localization	10 m (95 %)	-	12,5 m	60 s	1×10^{-2}/hour	< 0,1 % (TBC)	< 0,01 % (TBC)	TBD
Car accident reconstruction	Road	Reliable vehicle movement sensing	2 m (95 %)	99,5 %	5 m	60 s	1×10^{-5}/hour	< 0,1 % (TBC)	< 0,01 % (TBC)	TBD
Legal speed enforcement	Road	Reliable vehicle movement sensing	1 ms^{-1} (95 %)	99,99 %	7,5 m	30 s	1×10^{-5}/hour	< 0,1 % (TBC)	< 0,01 % (TBC)	TBD

5.4 Enabling technologies

This clause proposes an overview of the available technologies to implement the features of the location system. It is mainly focused at the terminal level, which traditionally embeds most of the relevant sensors. However, note that some technologies are also available at "system central facility" level (please refer to clause 3.1 Definitions). This point is however left open for a future release of the present document.

5.4.1 Terminal level

5.4.1.1 Sensor technologies

This clause proposes an overview of the sensor technologies proposed to be taken on-board as part of this standardization activity.

It is highlighted that the standardization activity executed here does not aim at standardising sensors detailed design. However, this inventory is done in order to define a realistic standardization framework. This way, we ensure that:

- when minimum performance which will be required in the framework of the present document is not an utopian one, that it will indeed be achievable with a given sub-set of sensor (typically: sub-millimetre accuracy for standalone mass market GNSS receiver is currently out of scope); or
- equivalently, when a standardized interface will be defined between two system elements, this definition does envision unrealistic components (typically: given the available data rates and sampling technology, requesting at GNSS receiver output a data flow containing RF signal samples is currently out of scope).

5.4.1.1.1 GNSS receiver

GNSS receiver is one of the core component of the terminal inside a location system. It is in charge of acquiring and tracking the signal coming from the GNSS receivers, and determine a number of parameters, mainly the position.

A GNSS receiver's performance of course depends on its characteristics. Two main categories of receivers, each one with its proper characteristics, are proposed to be considered:

- Mass market/low consumption GNSS receivers:
  - These receivers are the ones commonly encountered in Personal Navigation Devices and GSM/UMTS/LTE mobile handsets. Their main specificities are:
    - low power consumption;
    - reduced size;
    - important number of correlators.
- Liability critical receivers:
  - These receivers can be embedded in particular onto trains in order to for example to support some safety critical automatic train positioning functions. They can also be used for survey purposes (base station localization and time synchronization).

In the framework of the first release of the specification, it is proposed to address only the "mass market" GNSS receivers, which covers most of the targeted applications. Only train domain application might tend to use "liability critical receivers".

5.4.1.1.2 Inertial Navigation Sensor (INS)

Inertial navigation is based on the sequential processing of measurement performed by Inertial Reference Systems (IRS) sensors. Actually the objective is to transpose measurement results from the Galilean reference frame to reference frame more suited to navigation, such as the Earth Centred Earth Fixed (ECEF) reference frame. This transformation is mainly carried out using gyroscopes measurements. The accelerometer measurements are then expressed in a coordinate system adapted to navigation mode, and then integrated twice to obtain velocity and position. The basic relationship of inertial navigation is given below equation (1) with (m) and (n) respectively indicating "Mobile" (i.e. terminal) and "Navigation" reference frames.

$$\begin{bmatrix}\dot{v}_{North}\\ \dot{v}_{East}\\ \dot{v}_{Down}\end{bmatrix}^{(n)} = R_{m2n}\cdot\underbrace{\begin{bmatrix}f_x\\ f_y\\ f_z\end{bmatrix}^{(m)}}_{\vec{f}} + \underbrace{\begin{bmatrix}\xi_g\\ -\eta_g\\ g_n\end{bmatrix}^{(n)}}_{\vec{g}} - \left(\begin{bmatrix}\dfrac{v_{East}}{R_\Phi + h}\\ -\dfrac{v_{North}}{R_\lambda + h}\\ -\dfrac{v_{East}\cdot\tan(\lambda)}{R_\Phi + h}\end{bmatrix} + 2\cdot\begin{bmatrix}\omega_E\cdot\cos(\lambda)\\ 0\\ -\omega_E\cdot\sin(\lambda)\end{bmatrix}\right)\wedge\begin{bmatrix}v_{North}\\ v_{East}\\ v_{Down}\end{bmatrix}^{(n)} \quad (1)$$

- R_λ and R_Φ are the radius of curvature and the transverse radius of curvature respectively;
- h is the altitude;
- λ is the geodetic latitude of the mobile;
- v is the velocity of the mobile in the navigation frame;
- f is the acceleration measurements from the accelerometers;
- g is the local gravity vector;
- ω_E is the Earth's rotation rate ($\approx 7{,}292\,4 \times 10^{-5}$ rad/s = $4{,}17 \times 10^{-3}$ degrees/s).

Figure 10 illustrates the above fundamental INS mechanism.

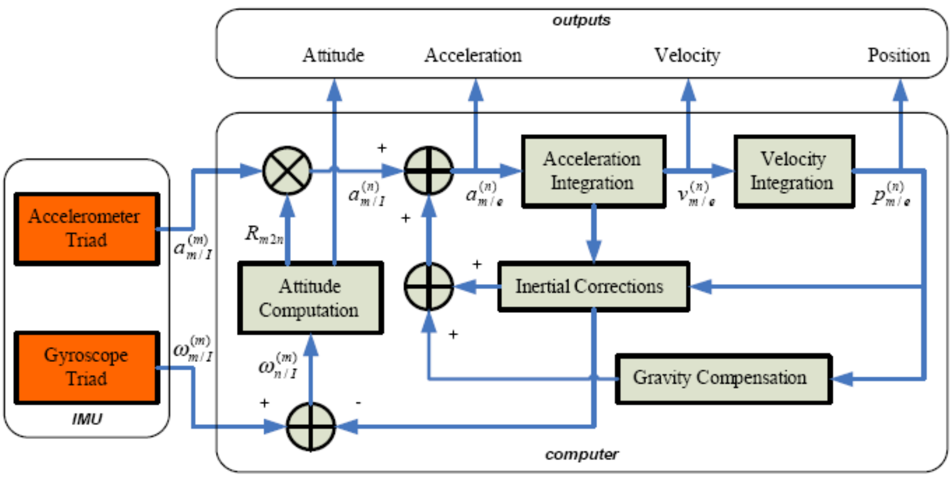


Figure 10: INS mechanism

Inertial sensor are necessary to obtain the required performances in difficult GNSS environments. Inertial sensor measurements are combined with GNSS measurements generally using Kalman filters. Three axes accelerometers and three axes gyroscopes are necessary.

Kalman filters may be of the "Tight" coupling type (hybridisation of GNSS pseudoranges, with accelerations and angles from inertial sensors), or of the "Loose" coupling type (hybridisation of GNSS positions, with positions computed from inertial sensors measurements).

Inertial sensors hybridization can act at different levels of the receiver processing chain:

- "Loose" coupling usually acts on Position, Velocity and Time (PVT) level data;
- "Tight" coupling implies processing at User Equivalent Range Error (UERE) level; and
- "Ultra-tight" coupling acts at lower level, i.e. at tracking loop level.

Hybridization algorithms could consider inputs from high-quality Inertial Measurement Unit (IMU) or low cost Micro Electro-Mechanical Systems (MEMS) as well.

As far as sensor type is concerned, it is proposed, for the moment, to restrain the panorama to the sensor complying with the following requirements:

- **at least one gyrometer;**
- **at least two accelerometers.**

Given this constraint eliminating single-accelerometer units, the end result will be almost exclusively Inertial Navigation Systems with three accelerometers and three gyrometers.

5.4.1.1.3 Communication network sensors

Most of the applications contemplated, if not all, require the use of mobile communication means. Thus, any kind of fleet management implies the use of a system central facility where the location information is reported and exploited, location based charging applications also suppose the use of the communication links between the remote terminal and the central facility in charge location authentication and billing, Assisted-GNSS positioning device needs to be connected to the location server via telecommunication network in order to be provided with assistance data.

Consequently, communication network sensors are part of the location system. It is worth considering also the aid that such mobile communication means may bring in terms of location: either to convey GNSS assistance data, and/or to provide coarse location (either using the network cell ID and associated coverage, or using advanced triangulation techniques, such as OTDOA).

5.4.1.1.4 Smart antenna

The antenna is a usual component of any GNSS receiver. In the mass market receivers, it is expected to comply with a number of high level requirements, in terms of size, pattern (omni, other), weight, possibility to merge it to the navigation device.

However, such constraints forbid the use of very antennas, proposed to be called "smart antenna", able to accomplish very valuable tasks in the frame of the RF local disturbance mitigation.

A typical such antenna is presented below. The proposed antenna is actually made of an array of 4 patches distributed as explained in figure 11.

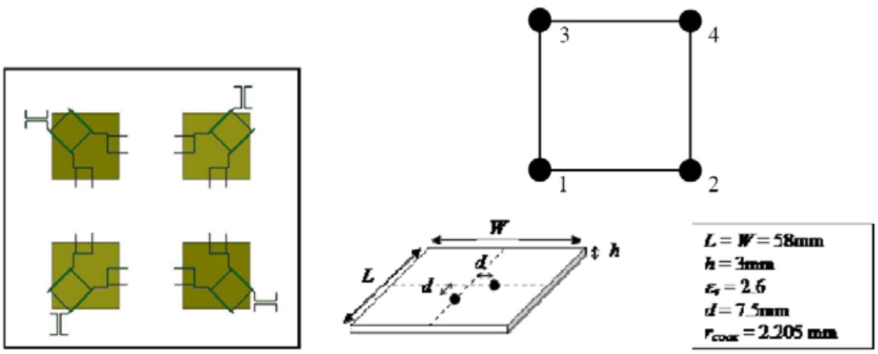


Figure 11: Antenna description - schematic (left) and geometric (right)

Indeed, antenna arrays perform a spatial sampling that makes possible the discrimination of sources in the space domain (azimuth and elevation). The use of antenna array algorithms is therefore proposed for two objectives:

- Electro Magnetic Interference **(EMI) mitigation**. Identifying the Direction Of Arrival (DOA) of the interference sources affecting the receiver then allows beam-form the antenna pattern, and minimizes the interference impact in terms of C/N0 loss. This is illustrated in the following figure 12.

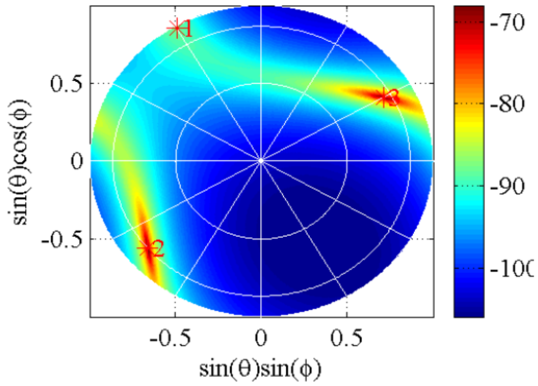


Figure 12: Interference DOA determination (3 sources)

- **Multipath (MP) mitigation:** If we assume that the space domain is independent of the time domain, we can expect to achieve MP mitigation, even for short delay MP which are usually badly isolated and mitigated with usual techniques (narrow correlator spacing, multiple estimating delay lock loop). Moreover, by combining the energy of the useful signals received by multiple antennas, the antenna arrays are able to significantly improve the performance of GNSS receivers under unfavourable signal conditions. This is illustrated in figure 13.

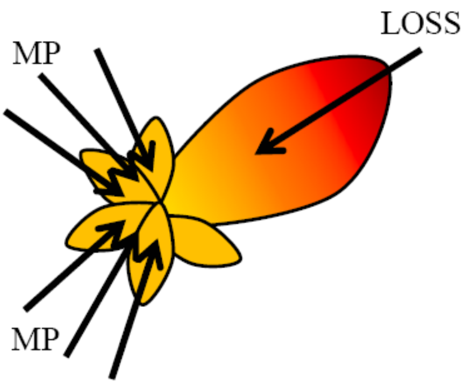


Figure 13: Multipath rejection and characterization

Two solutions are investigated to mitigate multipath with an antenna array:

- The first one tries to filter the multipaths in the space domain only in order to "**clean**" the incoming signal of all the multipaths. The time-delay and Doppler estimations of the Line Of Sight (LOS) signal are done after the space filtering step.

- In the second approach, a set of parameters (amplitudes, times-delays, Doppler shifts, elevations and azimuths) for all the incoming sources is estimated. The main difference between the approaches is that the parameter estimation in the second approach **explores the signal properties** on the space, time and frequency domains instead of just filtering the sources in the space domain only.

This capability is therefore very useful, not only for the improvement regarding interference rejection, but also for the possibility to characterize the multipath conditions. This is explored and detailed in clause 6.3.3 Protection Level.

5.4.1.1.5 Additional sensors

The list of sensors considered in the present document is limited to the above set. However, it does not mean that any additional sensor is irrelevant to location systems. The rationale behind this limited scope is derived from the objective of the present document, which is to demonstrate the relevancy of the proposed standardization work.

In order to make it clear, the following list of additional sensor which could possibly fall under the scope of the standardization task is proposed:

- Wi-fi modem.
- DVB modem.

5.4.1.2 Technology combination considered (system classes)

In the framework of the first release of the present document, it is proposed to focus on the following combination of technologies.

5.4.1.2.1 Type 1: standalone GNSS receivers

This category is quite explicit: it considers terminal imbedding only a GNSS receiver (including a **regular** antenna).

5.4.1.2.2 Type 2: GNSS receivers combined with inertial sensor

The hybridization of two navigation systems is the computation of a sought final data (position, speed, heading) from intermediate data provided by these two systems. The idea behind this association is to develop a hybrid system more robust to interference and multipath, and more accurate.

In the case of satellite navigation and inertial, the accuracy of short-term inertia is complementary to the long-term accuracy provided by GNSS navigation. In addition:

- errors associated with the changing RF environment where the terminal evolves only affect the satellite navigation system; and
- the drifts observed on the measurement of the INS are not reflected in GNSS measures.

There are several ways to hybridize a GNSS receiver with an INS. These methods depend on the type of measurement available at the output of the GNSS receiver. In case the information of position and velocity are available, integration can follow a "**loose" coupling** method. In case the raw measurements of the receiver are available (that is to say pseudorange, Doppler measurements, etc.), a **"tight"** coupling may be executed. Finally, if it is possible to have access to the heart of the chip processing and more particularly to GNSS tracking loops, integration "**ultra-tight**" can be implemented.

The integration method depends on the type of chosen application, on the environment in which the hybrid system will be assessed, and on the targeted complexity of the integrated system. Whatever method is finally chosen, the combination of measures is usually performed through a Kalman filter. Two implementations are possible for each integration method: open loop and closed loop:

- **Open loop:** the INS measurements are corrected by the GNSS measurements when they are available. These corrections are calculated from time to time in the filter data fusion, and are not stored in memory. The INS system operates autonomously, with no need of external information.
- **Closed loop:** some of the filter outputs are sent back to the INS input, in order to correct for sensor errors (bias, scale factor, etc.) and allow more precise navigation.

Figures 14, 15 and 16 summarize the available implementations described above.

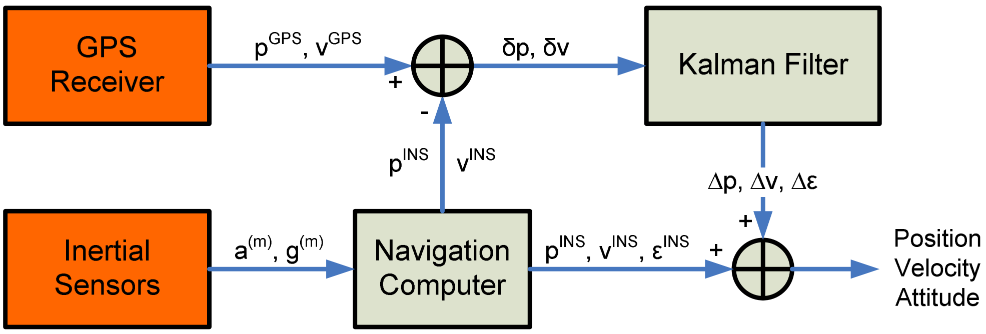


Figure 14: Loose coupling, open loop

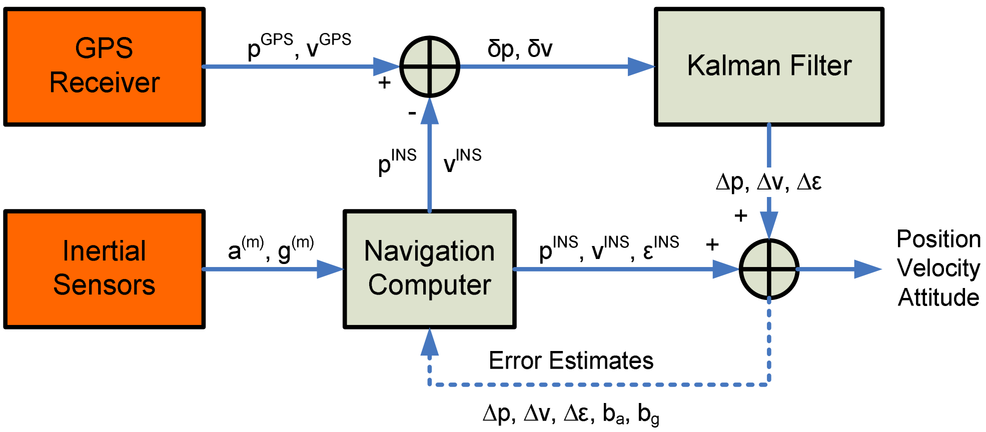


Figure 15: Loose coupling, closed loop

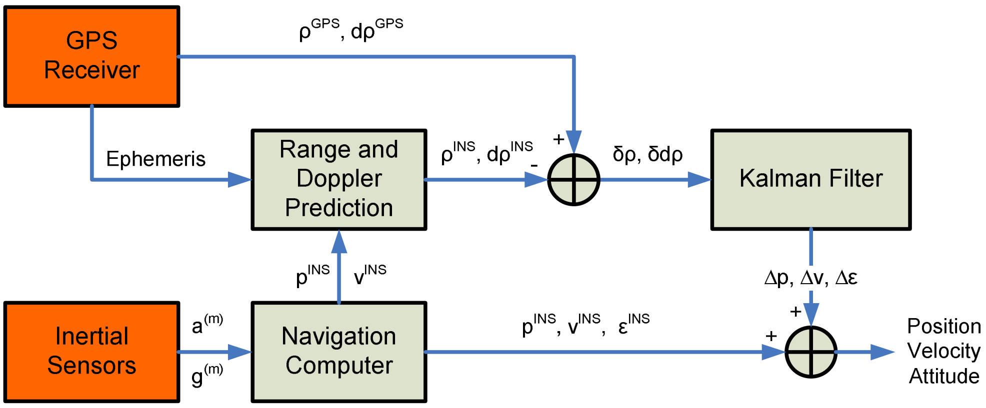


Figure 16: Tight coupling, open loop

NOTE: The diagram of tight coupling with closed loop is derived from figure 16 the same way figure 15 is derived from figure 14.

Table 3: Hybridization techniques advantages and drawbacks

Coupling	Pros	Cons
Loose	• Most simple hybridization technique • Navigation sensors independence is ensured (open loop) • Provides a navigation solution redundant with the one provided by systems	Do not take into account GNSS information if the number of used satellites is below 4 (maybe often the case in urban light or dense)
Tight	• Position solution more accurate than for loose coupling (using measures with equivalent quality) • Allow user to take advantage of GNSS satellite even if less than 4 satellites are visible • Allow implementation of techniques enabling identification and rejection of erroneous measurement (good for position confidence level)	• Do not make available the position solution computable from the secondary navigation system measurements (GNSS) • Complex implementation (nonlinear equations, setting and monitoring of divergence of the filter, etc.) • Forces to have access to satellite ephemeris used in the hybrid solution • Accurate synchronization required
Ultra Tight	• Improves robustness versus interference and jamming	• Important interaction between GNSS receiver and INS • High coupling complexity • Very accurate synchronization required

5.4.1.2.3 Type 3: GNSS receivers combined with smart antenna

This category considers terminal embedding a GNSS receiver together with a smart antenna, replacing the regular antenna.

This combination is considered relevant for the following reasons:

- First, the use of a smart antenna allows significant interference mitigation via the enabled beam forming. This is crucial importance when dealing with constrained environments, such as industrial areas.
- Second, the same feature is also (partly) applicable to multipath, allowing a significant reduction of the MP contribution to the GNSS measurement error.
- Third and last, this combination offers a very promising mean to characterize the RF environment (including interference and multipath). This characterization is of key importance, in particular for any liability critical application where protection level associated to the position is computed. Indeed, we have seen previously that local error sources are the most impacting one: having a way to bound them enables the determination of a more accurate protection level.

5.4.1.2.4 Additional types of terminal

The list of terminal types considered in the present document is limited to the above set. However, it does not mean that any additional type of terminal is irrelevant to location systems. The rationale behind this limited scope is derived from the objective of the present document, which is to demonstrate the relevancy of the proposed standardization work.

Thus, a type of terminal embedding both a GNSS receiver and a communication modem is already considered relevant. It is indeed the main type of terminal considered in any Assisted GNSS techniques, widely addressed in 3GPP.

5.4.2 System central facility level

This clause is to be completed in a future release of the present document.

5.4.3 Telecommunications systems

Different communications systems can be considered to support the connection between the positioning terminal and the location system central facility.

Depending on the type of location system considered, this connection can be established either using a wired communications (for instance for types of systems were positioning sensors, system central part and application data are located in a single handset, such as city sightseeing), or using radio communication systems, from Wi-Fi (indoor warehouse assets management) to terrestrial mobile communication systems (road charging) and satellite based systems (e.g. person or animal tracking).

To that point of the analysis, it is considered worthwhile listing the characteristics of the main radio communication systems, in order to be able to clearly identify the constraint in terms of coverage, data rates and availability.

There are two possible classes of systems and table 4 summarises different possible systems that can be used:

- Terrestrial systems.
- Satellite based systems.

Table 4: Typical cellular and mobile satellite systems

System	Mode (sat or terrestrial) and brief description	Coverage	Services and Possible rates	Terminals
2G, 2,5G, and 2,75G systems	Terrestrial • GSM • GPRS • EDGE	Quasi-Universal in Europe	Voice and data GSM: around 10 kbits/s GPRS-EDGE: from 56 kbits/s to 130 kbits/s	Handsets/ Handhelds/ PDA/ Smart phones
3G and 3G+	Terrestrial: 3GPP and 3GPP2	Urban/Suburban and rural (around 90 % population in France	Voice and data From 300 kbits/s to around 7 Mbit/s	Handsets/ Handhelds/ PDA/ Smart phones
LTE (4G)	Terrestrial	Urban/Suburban	Voice and data Up to 100 Mbits/s down and 50 Mbis/s up	Smart phones
Globalstar	Satellite: 48 satellites in LEO orbits Second generation under launch	Universal up to 70 ° latitude (N and S) (but outdoor coverage)	Voice and data Up to 9 600 bits/s	Handheld Vehicle mounted terminals Usually multimode terminals
Iridium	Satellite 66 satellites in polar LEO second generation under design	Universal) (but outdoor coverage)	Voice and data 1st Generation: up to 9 600 bits/s 2nd Generation: up to 512 kbits/s up and up to 1,5 Mbits/s down	Handheld and vehicle mounted terminals for 1st generation Bigger terminals for 2ndgeneration
THURAYA	3 Satellites in GEO orbit	Middle East /Africa/ India/ Europe/ Australia/ Central Asia	Voice and data Voice/fax up to 9 600 bits/s Data up to 60 kbits/s down and 15 kbits/s up for handheld Up to 400 kbits/s laptop like terminal	Handheld Vehicle adapted terminals Laptop like terminals
INMARSAT 4	3 Satellites in GEO orbit	Whole world (sea and lands)	Voice and data Up to 20 kb/s handhelds Up to 400 kb/s laptop like terminal	Handheld Vehicle adapted terminals (maritime, aircrafts) Laptop like terminals
Terrastar	TBD	TBD	TBD	
MEXSAT	TBD	TBD	TBD	
WI-FI				

5.5 Operational environments

As mentioned in the introduction, part of the proposed standardisation work will deal with the definition of operational environments. Indeed, the definition of minimum performance specifications for location systems and terminal highly depends on the environment of the system, and in particular of the terminal.

This clause therefore aims at defining a set of operational environment to be used in the framework of the standard production. It first lists the environment characteristics deemed relevant in the fixed technical perimeter, then builds a set of typical environments intended to be representative for a wide diversity of realistic environments, and finally provides characteristics of each of these environments.

NOTE: The preliminary definition of location system performance proposed in clause 6 Preliminary system architecture and performance uses the operational environment thus defined as reference environments.

5.5.1 Environment characterisation criteria

An environment can be described by the following criteria:

- **Mask Angle:** A fixed elevation angle referenced to the user's horizon below which satellites are ignored by receiver software. Mask angles are used primarily in the analysis of GNSS performance, and are employed in some receiver designs. The mask angle is driven by the receiver antenna characteristics, the strength of the transmitted signal at low elevations, receiver sensitivity and acceptable low elevation errors (see RTCA DO-229D [i.2]).

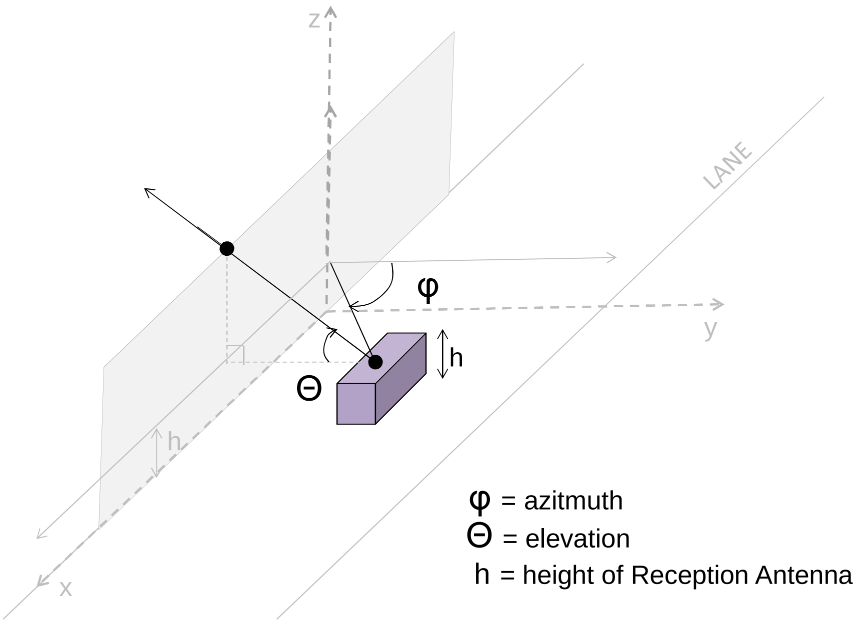


Figure 17: Elevation mask

- **Signal Attenuation:** Signal attenuation refers to any decrease of GNSS signal power at the level of reception antenna. The attenuation, expressed in decibel (dB), corresponds to the rate between the power of GNSS signal at receiver antenna level and the nominal GNSS signal power - at the emission.
- **Multipath:** Signal arrival at a receiver's antenna by way of two or more different paths such as a direct line-of-sight path and one that includes reflections off nearby objects. The difference in path lengths causes the signals to interfere at the antenna and can corrupt the receiver's pseudorange and carrier-phase measurements. In some cases, the direct line-of-sight signal can be obstructed: the antenna only receives the multipath signal.
- **Interference:** Interference denotes emission of signals in bands close to GNSS's, which are disturbing GNSS signals. These emissions can be transmitted unintentionally or intentionally. Jamming denotes intentional emission of signals with the objective to disturb or interrupt the GNSS services.

- **User dynamic:** User dynamic corresponds to the dynamic of the mobile target and represents its attitude. It is characterized by the velocity, acceleration and jerk of the terminal.

In addition to the above mechanical and electromagnetic characteristics, two additional parameters also need to be considered in order to define the system/terminal environment:

- Temperature;
- Humidity.

5.5.2 Definition of operational environments

This clause defines seven generic user environments. These seven generic environments are sufficient to describe any user environment.

5.5.2.1 Open area

"Open area" generic environment represents the best use case. The user is in open area with clear sky view. The level of received signal is nominal. The satellites can be viewed in line of sight over 5 degrees of mask angle. This environment is also characterized by the absence of interference or multipath. Some examples of this environment are open sea or land environment without building, tree, natural obstacle or metallic structure.

5.5.2.2 Rural area

"Rural area" generic environment is mainly characterized by the presence of dense vegetation. A dense foliage along the lane can cause a mitigation, even an obstruction, of the GNSS signal and create multipath conditions. In this type of generic environment the interference occurrence is considered as scarce. Some examples of "Rural area" are parkland, forest or country.

5.5.2.3 Suburban area

"Suburban area" generic environment is characterized by small blocking structures, buildings or natural geographical obstacles. The risk of interference and multipath is considered as low. Some examples of this environment are small population centre without tall building, residential district, port approach area, inland waterways on a wide river, restricted water.

5.5.2.4 Urban area

"Urban area" generic environment is characterized by high rise structures, buildings or natural geographical obstacles. It also corresponds to a densely constructed area. The risk of multipath is high. Some examples of this environment are urban canyon, cutting, port area or inland waterways on a narrow river. The risk of interference is considered as medium.

5.5.2.5 Covered area

"Covered area" generic environment is characterized by a loss of the GNSS signal. Some examples of covered area are in-door conditions, tunnels, stations or bridges.

5.5.2.6 Asymmetric area

"Asymmetric area" generic environment is characterized by different across-line mask angle. Lane alongside cliff and lane with building or trackside structure on one side only are examples of asymmetric area. It can also be considered as a semi "Urban area".

5.5.2.7 Industrial area

"Industrial area" generic environment is characterized by the presence of metallic structures, radio sources, cables, overhead lines, gantries, catenaries, intentional or un-intentional jammer. The number of multipath and the related error are high. There is also a high interference risk due to increased radio signal presences related to industrial activity.

5.5.3 Generic environments characterisation

Table 5 provides the characterisation of the generic environments according to the aforementioned criteria.

Table 5: Operational environment definition

Environment	Examples	Main characteristics	Criteria	Characterisation Assessment
Open area	Open sky Land environment without building, tree, natural obstacle or metallic structure Open sea	Best use case Clear sky view Absence of interference or multipath	Elevation Mask (°)	0 ° - 5 °
			Multipath	null
			Attenuation	low
			Interference risk	null
			User Dynamic	Pedestrian, Road, Rail, Maritime
Rural area	Parkland, forest, country Motorway apart from urban canyon Coastal area	Presence of dense vegetation along the lane Mitigation, even obstruction, of GNSS signals Multipath conditions	Elevation Mask (°)	0 ° - 15 °
			Multipath	low
			Attenuation	medium - high
			Interference risk	low
			User Dynamic	Pedestrian, Road, Rail, Maritime
Suburban area	Residential district Port approach area Inland waterways (wide river) Restricted waters Small population centre	Small blocking structures, buildings or natural geographical obstacles Multipath conditions	Elevation Mask (°)	0° - 30°
			Multipath	medium
			Attenuation	low
			Interference	low
			User Dynamic	Pedestrian, Road, Rail, Maritime
Urban area	Urban canyon Cutting Port area Inland waterways (narrow river)	High rise structures, buildings or natural geographical obstacles Densely constructed area Multipath conditions	Elevation Mask (°)	10° - 60°
			Multipath	high
			Attenuation	medium
			Interference	low
			User Dynamic	Pedestrian, Road, Rail, Maritime
Covered area	Tunnels Stations Bridges	GNSS Signal loss	Elevation Mask (°)	
			Multipath	
			Attenuation	
			Interference	
			User Dynamic	Pedestrian, Road, Rail, Maritime
Asymmetric area	Road alongside cliff Road with buildings on one side only Trakcsides structures on one side only T-junctions X-roads	Different across-line mask angle Semi- "Urban area"	Elevation Mask (°)	0 ° - 30 ° *first side* 30 ° - 60 ° *second side*
			Multipath	high
			Attenuation	medium
			Interference	low
			User Dynamic	Pedestrian, Road, Rail, Maritime

Environment	Examples	Main characteristics	Criteria	Characterisation Assessment
Industrial area	Radio sources Cables Overhead lines Gantries Catenaries	Metallic environment Intentional or un-intentional jammer Multipath conditions Interference conditions	Elevation Mask (°)	0 ° - 60 °
			Multipath	high
			Attenuation	medium
			Interference	high
			User Dynamic	Pedestrian, Road, Rail, Maritime

Furthermore the user dynamics are proposed to be defined as follows in table 6.

Table 6: Operational environment - user dynamics

User dynamic	*Velocity (ms^{-1})*	*Accelaration (g)*	*Jerk (gs^{-1})*
Pedestrian	TBD	TBD	TBD
Road	TBD	TBD	TBD
Rail	TBD	TBD	TBD
Maritime	TBD	TBD	TBD

6 Preliminary system architecture and performance

6.1 Introduction

As already exposed in introduction to the present document, the on-going standardization initiative comes from the observation that in many various standardization bodies, performance of location technologies are specified independently from one another leading to:

- Inconsistent GNSS-related requirements from one group to the other.
- Lack of expertise in given groups leading suboptimal requirements.
- Slow market uptake of GNSS technologies.

The purpose of such enterprise is to concentrate all the GNSS standardisation efforts in a single group, therefore offering a valuable support to other standardisation groups/bodies for what concerns GNSS.

As far as implementation is concerned, the GNSS Minimum Performance Standard (MPS) under construction is seen as dictionary made available for any standardization body willing to include GNSS-related location technology in their technical specification.

To that end, the MPS definition has been split into 4 main streams of activities:

- **Definition of the list of application intended to be addressed by the MPS.** Given the objective, the wider is this list, the more exploitable will be the resulting document. This activity should also inventory the key requirements (functional or performance) applicable for each application.
- **Inventory of the technologies "available" to comply with the specific needs of all applications listed in the previous activity.** These technologies are understood as much as sensor technologies (GNSS receivers, network sensors, inertial sensors, hybridization layer), as system layer feature allowing QoS improvements (A-GNSS, D-GNSS, Real Time Kinematic (RTK), integrity functions, authentication functions).
- **Definition of reference environments.** Definition of minimum performance should indeed take into account typical environment associated to the application use cases, since they are major drivers of the achievable performance. In addition, since a specific focus is made in the multi-modal application, changing environment is a key factor to take into account.
- Finally, the last activity is the standardization activity which is proposed to be focussed on two aspects:
    - A standardization of the interfaces between the various possible components of location system. This activity is based on the applications and sensors inventory executed, in order to determine a typical high level reference architecture, and thus define the interface standard.
    - The definition of the MPS itself: for each application, whose performance is worthy of standardization, and for each considered technology and environment, what is the level of performance to be specified?

In addition to the above general objective, it is deemed important to determine how the various releases of the standard will be produced (see clause 7.3 Evolution plan).

6.2 Reference architecture

6.2.1 Stage 1 architecture

6.2.1.1 Logical reference model

Figure 18 shows the logical reference model for the standardization carried out. Please refer to clause 3.1 Definitions for a definition of the description of the components outside the location system perimeter (outside of the framework of this architecture).

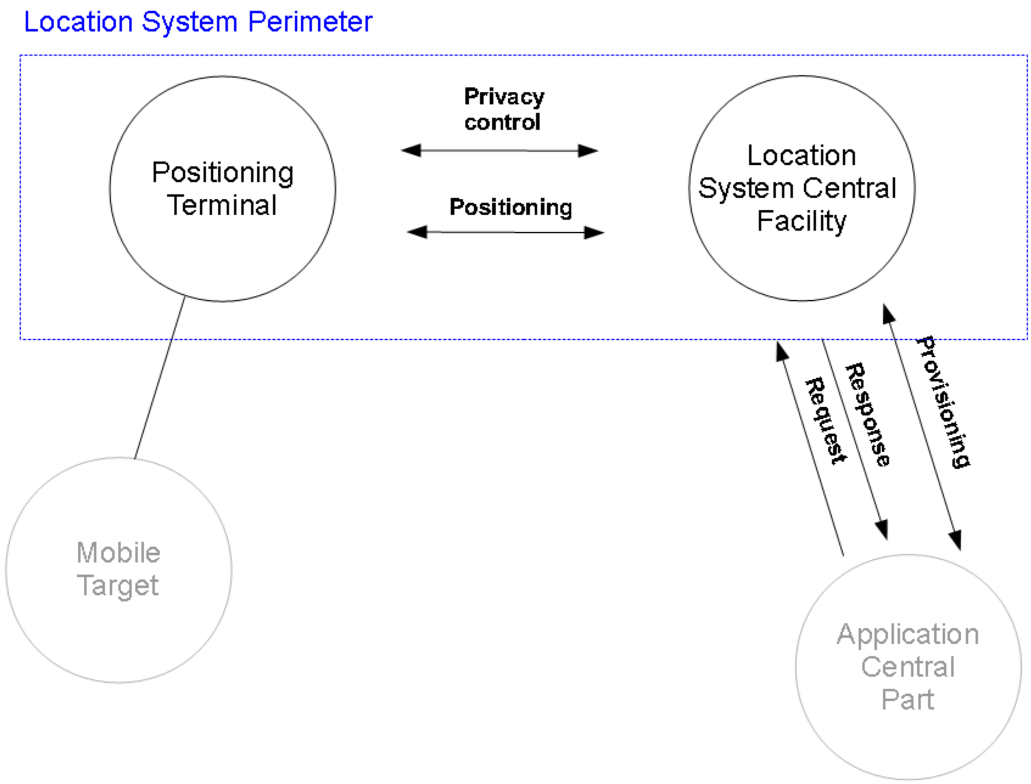


Figure 18: Stage 1 architecture

6.2.1.2 Functional entities

- Application central part:
  - The application central part is a logical functional entity that makes a request to the location system for the location information of one or more than one target terminal within a specified set of parameters such as Quality of Service (QoS). The application central part may reside inside or outside a terminal. The specification of the application central part internal logic and its relationship to any external user (e.g. Requestor) is outside the scope of the present document.
- Location system central facility:
  - A location system central facility consists of a number of location service components and bearers needed to serve the application central part. The location system central facility may respond to a location request from a properly authorized application central part with location information for the target terminal specified by the application central part if considerations of terminal privacy are satisfied. The location system central facility may enable an application central part to determine the services provided to it by the location system central facility through a process of provisioning.

- Positioning terminal:
  - The terminal is the object to be positioned by the location system. The ability to control privacy may be required to be given to the terminal user for each location request and/or to the terminal subscriber through the terminal subscription profile to satisfy local regulatory requirements.
- Positioning function:
  - Positioning is the basic function that performs the actual positioning of a specific target terminal. The input to this function is a positioning request from the application central part, with a set of parameters such as QoS requirements. The end results of this function are the location information for the positioned target terminal.
- Mobile target:
  - The mobile target is the entity (vehicle, person, goods, etc.) to which the positioning terminal is attached. In the frame of the location system, the terminal position is supposed to be representative of the mobile target position.

6.2.1.3 Functional Interfaces

Function interfaces are further described in the following clauses, dedicated to stage 2 architecture.

6.2.2 Stage 2 architecture

The objective of this clause if to propose a more detailed system architecture in order to support the standardization work proposed. Consequently:

- It includes the various components needed in order to implement the location key features defined in clause 5.2 Location systems key features.
- It defines the associated main interfaces between these components. In particular, it is targeted to define the message flows.
- Proposed architecture needs to be flexible enough in order to be applicable at least for the perimeter of applications addressed in the first release of the standard.

The selected architecture is as shown in figure 19.

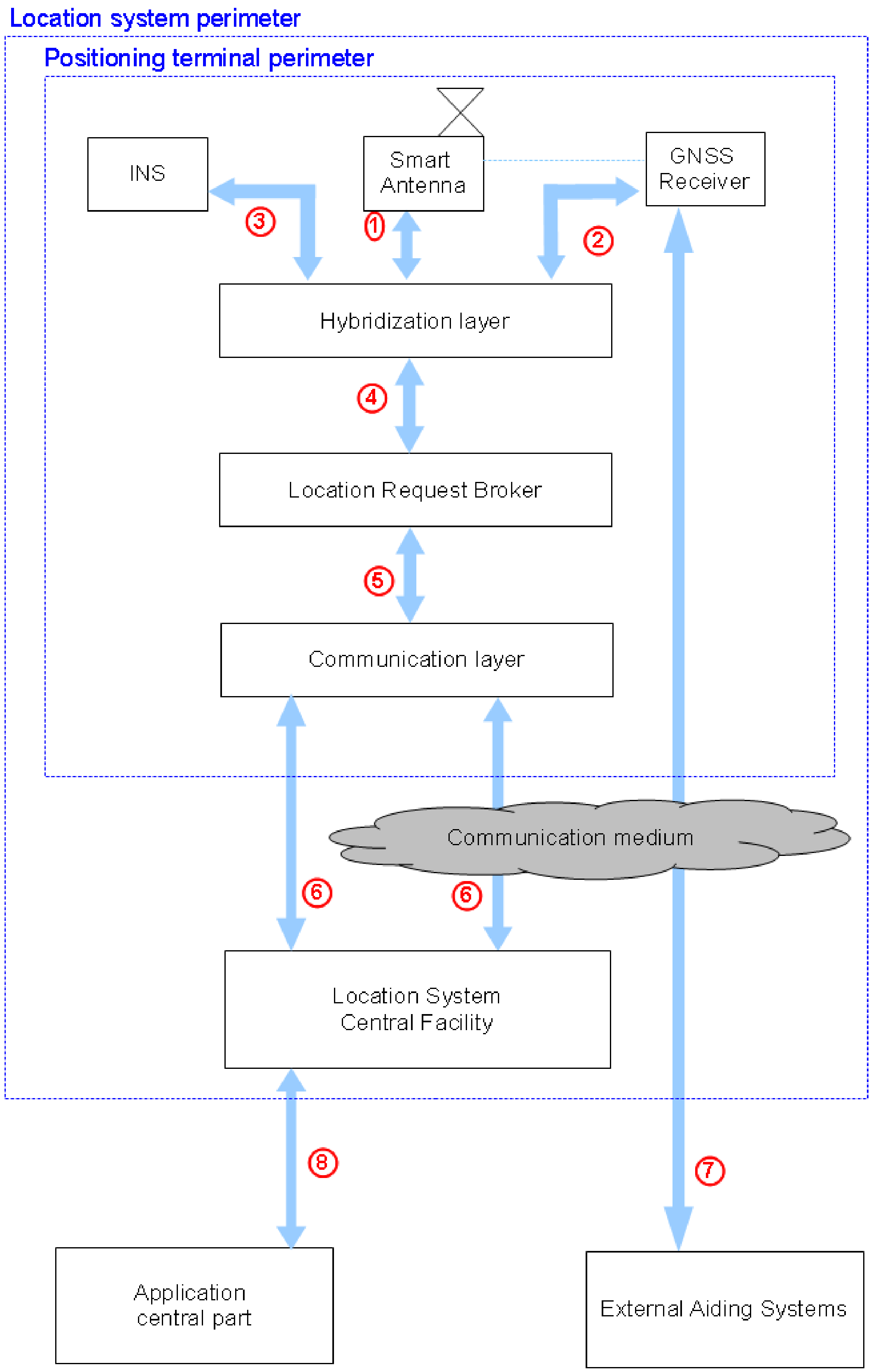


Figure 19: Stage 2 architecture

The various components shown in figure 19 are described here below:

GNSS receiver:

This component is in charge of acquiring and tracking the RF signals coming from the various supported GNSS constellations, and measures a given number of parameters related to the terminal position and movement. Further details on the supported measurement are given in the interface description.

INS - Inertial Navigation Sensor:

This component is in charge of measuring the terminal 3D acceleration and rotations. It can possibly derive some parameters concerning terminal attitude. Further details are given in the interface description.

Hybridization layer:

The hybridization layer is in charge of processing the location request provided by the Location request broker. This processing implies in particular the activation of the specified sensors (INS, GNSS, others). Further details are given in the interface description.

Location request broker:

The location requests broker role is to handle the location (and control) requests initially originated by the location system central facility, and to satisfy them by providing the location response and status with the assumption that it receives a continuous flow of location information from the hybridization layer.

Communication layer:

The communication layer is in charge of establishing the physical link between the location system central facility on one hand, and the terminal including the various selected sensors on the other hand.

The communication layer is understood as a very general term: for application such fleet management, it establishes link between central management facility and the deployed assets (in this case, link can be terrestrial telecommunication link, UHF, other), whereas for application such as personal navigation, application central part is inside the terminal itself (device MMI), so that communication is internal to the terminal.

Location system central facility:

The central facility is in charge of managing the requests coming from a third party application providers, addressing the requests to the positioning terminal(s), and implementing part of the location determination functions. As illustrated above, it can be inside or outside the positioning terminal.

Application central part:

The application central part is the core of the application in charge for emitting location requests. As illustrated above, it can be inside or outside the positioning terminal.

External aiding systems:

This designates aiding systems that are inside a given external infrastructure. Typically, this is the case of the Assisted GNSS server that belongs to mobile telecommunication infrastructures.

All the above components are expected to exchange a given amount of information according to a given protocol. These interfaces are described in the following clauses. The interfaces 7 and 8 in figure 19 are not described so far (external to the system).

6.2.2.1 Interface 6

Interface 6 takes place between the positioning terminal and the central facility, which is at the origin of the location request.

The main transactions occurring on this interface are:

- Location request/response: The location can be either:
    - immediate;

- periodical (hence generating several responses);
- or event triggered (e.g. when the positioning terminal sends its location when entering/exiting a specific geographical zone); or
- constrained by the minimum QoS to be satisfied.

The Location request/response transaction supports the necessary features to ensure privacy management. Typically the OMA Secure User Plane for Location (SUPL) specification, OMA-TS-ULP-V2_0-20100816-C [i.3], is a good basis for such implementation. The transaction may end by an explicit stop message or can stop following a timer or event condition defined in the location request. In this latter case the last response message includes an indication of such terminaison case.

- Control/status transaction. A control may change the operational status of the positioning terminal, with an impact on the way the positioning terminal is reporting its position (e.g. if a control requests the positioning terminal to switch in a diagnosis mode, then, the terminal location response may be more verbose).

Both these transactions may convey application specific data, fully depending on the application which is addressed. At this stage, the present document just imposes that the interface has the capability to convey such data.

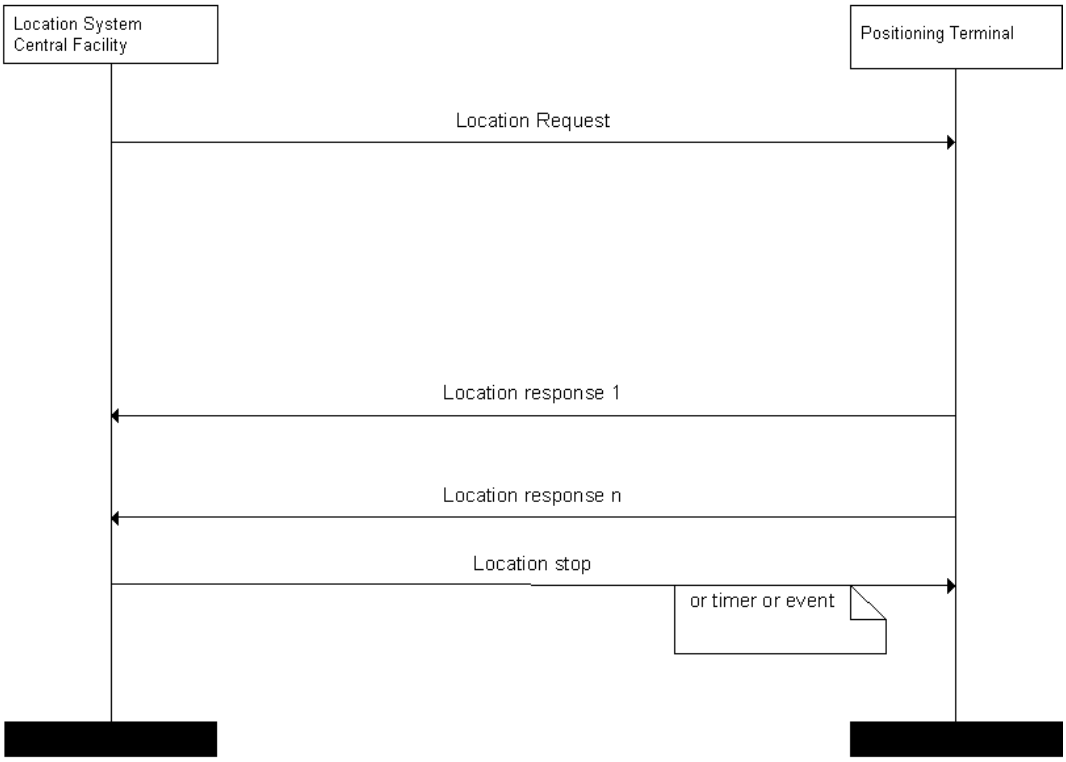


Figure 20: Location request/response transaction

Location responses can contain for each position fix:

- the PVT solution;
- the type of location technique applied (standalone GNSS, assisted GNSS, type of hybridisation, etc.);
- the QoS attached to the position fix (level of confidence);
- PVT solution GNSS input data (for GNSS: Satellite Vehicle (SV) pseudoranges, SVs C/N0, etc.) (optional or/on request);
- PVT solution Sensors input data: TBD depending on the sensors (optional or/on request).

Figure 21: Control/status transaction

6.2.2.2 Interface 5

Interface 5 bears the same semantics as interface 6.

6.2.2.3 Interface 4

The location requests broker role is to handle the location (and control) requests presented above, and to satisfy them by providing the location response and status, on interface 5, with the assumption that it receives a continuous flow of location information from the hybridization layer.

Thus the location request broker:

- Handles the location requests that may be received in parallel from several applications.
- Handles the necessary timers/location history to generate the appropriate location responses for periodical or trigger location requests.
- Handles the control/status transactions, by feeding the location responses with the appropriate status and location data depending on the mode requested by the control requests.

Bearing this in mind, the interface 6 becomes rather simple. After the necessary initialization phase and possible reset controls received by the Location requests broker, a continuous and periodical location messages flow is exchanged on this interface, until the location request broker sends a stop message.

Figure 22: Interface 4 continuous location message exchange

The location message conveys the most detailed location data, whatever the location request to be satisfied. It is up to the location request broker to filter the data if necessary.

Thus the location message on interface 5 conveys in any case:

- the PVT solution;
- the type of location technique applied (standalone GNSS, assisted GNSS, type of hybridisation, etc.);
- the QoS attached to the position fix (level of confidence);
- PVT solution GNSS input data (for GNSS: SVs pseudoranges, SVs C/N0, etc.);
- PVT solution Sensors input data: TBD depending on the sensors;
- hybridization layer status information.

6.2.2.4 Interface 3

Interface 3 conveys the necessary data in order to enable the hybridization task.

Content of the interface depends on the hybridization depth adopted (see clause 5.4.1.2.2 Type 2: GNSS receivers combined with inertial sensor).

Table 7 provides the list of parameters expected to be exchanged on this interface, together with the associated type of hybridization for which they are needed (for information).

Table 7: Interface 3 content

Parameter	Description	Interface direction	Unit	Associated hybridization depth
P_{INS}	Position estimate coming from the INS	Hyb ← INS	m	All
V_{INS}	Speed estimate coming from the INS	Hyb ← INS	m/s	All
δPos	Error on sensor position (from INS)	Hyb → INS	m	All
δV	Error on sensor speed (from INS)	Hyb → INS	m/s	All
δAtt	Error on sensor attitude (from INS)	Hyb → INS	rad	All
δAccel	Error on sensor acceleration (from INS)	Hyb → INS	m/s^2	All
δGyro	Error on sensor gyroscopes (from INS)	Hyb → INS	rad/s	All
P_{GNSS}	Position estimate coming from GNSS sensor	Hyb → INS	m	All
V_{GNSS}	Speed estimate coming from GNSS sensor	Hyb → INS	m/s	All

A same type of transaction is assumed as for interface 4 (init/reset messages, followed by a periodical messages suite, ending with a stop message).

6.2.2.5 Interface 2

Interface 2 conveys the necessary data in order to enable the hybridization task.

Content of the interface depends on the hybridization depth adopted (see clause 5.4.1.2.2 Type 2: GNSS receivers combined with inertial sensor).

Table 8 provides the list of parameters expected to be exchanged on this interface, together with the associated type of hybridization for which they are needed (for information).

Table 8: Interface 2 content

Parameter	Description	Interface direction	Unit	Associated hybridization depth
P_{GNSS}	Position estimate coming from the GNSS sensor	Hyb ← GNSS	m	Loose
V_{GNSS}	Speed estimate coming from the GNSS sensor	Hyb ← GNSS	m/s	Loose
δPos_{3D}	Uncertainty on sensor position (from GNSS)	Hyb ← GNSS	m	Loose
δV_{3D}	Uncertainty on sensor speed (from GNSS)	Hyb ← GNSS	m/s	Loose
$\{\rho_i\}_{i=1:N}$	Pseudorange for the N GNSS satellites used in the position solution	Hyb ← GNSS	m	Tight
$\{\dot{\rho}_i\}_{i=1:N}$	Accumulated Doppler for the N GNSS satellites used in the position solution	Hyb ← GNSS	m/s	Tight
$\{\delta\tau_i\}_{i=1:N}$	Numerically Controlled Oscillator (NCO) commands for the GNSS code loop discriminator steering (for N tracked Satellites)	Hyb → GNSS	s	Ultra-tight
$\{\delta\varphi_i\}_{i=1:N}$	Phase command for the GNSS phase loop discriminator steering (for N tracked Satellites)	Hyb → GNSS	rad	Ultra-tight
$\{dop_i\}_{i=1:N}$	Doppler applicable for the N current Line Of Sight (LOS)	Hyb → GNSS	Hz	Ultra-tight
H	Heading	Hyb ← GNSS	rad	N/A
φ	Carrier phase	Hyb ← GNSS	m	N/A
d	Carrier Doppler	Hyb ← GNSS	Hz	N/A

A same type of transaction is assumed as for interface 4 (init/reset messages, followed by a periodical messages suite, ending with a stop message).

6.2.2.6 Interface 1

The interface 1 takes place between the smart antenna and the hybrization layer. It conveys all data related to interference and multipath mitigation. This data is described in the following table 9.

Table 9: Interface 1 content

Parameter	Description	Interface direction	Unit
$\{DoA_i\}_{i=1:J}$	Directions of arrival of the J detected jamming signals	Hyb ← Ant	rad²
$\{P_i\}_{i=1:J}$	Speed estimate coming from the GNSS sensor	Hyb ← Ant	dBW
$\{f_i\}_{i=1:J}$	Uncertainty on sensor position (from GNSS)	Hyb ← Ant	Hz
$\{DoA_k\}_{k=1:M}$	Directions of arrival of the M detected delayed signals	Hyb ← Ant	rad²
$\{D/U_k\}_{k=1:M}$	Relative power of the M detected delayed signals (compared to main Desired signal)	Hyb ← Ant	dB
$\{\tau_k\}_{k=1:M}$	Delays of the M detected delayed signals (compared to main Desired signal)	Hyb ← Ant	s

6.3 Performance requirements

Reminder:

- GNSS signals considered: GPS L1C/A, L1C, L2C, L5, Galileo E1 (incl. PRS), E6 (incl. PRS), E5, GLONASS G1, G2, QZSS L1C/A, L1C, L2C, L5, SBAS L1. Minimum Performance displayed below has to be understood as "for any GNSS used".
- The **types** of terminal considered below are described in clause 5.4.1.2 Technology combination considered (system classes).
- The **environments** considered below are defined in clause 5.5 Operational environments.
- The performance key features successively addressed below are described in clause 5.2 Location systems key features.

6.3.1 Horizontal accuracy

The horizontal accuracy performance is specified through the following figures of merit:

- Availability rate, expressed as a percentage. It represents the percentage of time when position solution is available.
- Various percentiles of the Horizontal Position Error (HPE) distribution. HPE is defined by the horizontal difference in meters between the ellipsoid point reported or calculated from terminal response and the actual position of the terminal in the test case considered.

Table 10: Horizontal accuracy minimum performance

Terminal type	Figure of merit	Open area	Rural area	Suburban area	Urban area	Covered area	Asymmetric Area	Industrial area
Type 1	Availability	100 %	100 %	98 %	98 %	0 %	99 %	95 %
	HPE - mean	TBD	TBD	TBD	TBD	N/A	TBD	TBD
	HPE - 95 %	30 m - TBC	30 m - TBC	60 m - TBC	100 m - TBC	N/A	100 m - TBC	120 m - TBC
	HPE - Max	250 m - TBC	250 m - TBC	250 m - TBC	250 m - TBC	N/A	250 m - TBC	300 m - TBC
Type 2	Availability	100 %	100 %	100 %	100 %	100 %	100 %	100 %
	HPE - mean	2 m - TBC	2 m - TBC	5 m - TBC	15 m - TBC	Special	3 m - TBC	18 m - TBC
	HPE - 95 %	3 m - TBC	3 m - TBC	10 m - TBC	25 m - TBC	Special	5 m - TBC	30 m - TBC
	HPE - Max	10 m - TBC	10 m - TBC	50 m - TBC	70 m - TBC	Special	15 m - TBC	80 m - TBC
Type 3	Availability	100 %	100 %	90 %	85 %	0 %	90 %	95 %
	HPE - mean	Idem type 1	Idem type 1	TBD	TBD	N/A	TBD	TBD
	HPE - 95 %	Idem type 1	Idem type 1	40 m - TBC	70 m - TBC	N/A	70 m - TBC	70 m - TBC
	HPE - Max	Non-specified	Non-specified	Non-specified	Non-specified	N/A	Non-specified	Non-specified

As far as performance assessment of type 2 terminals is concerned, the case of **covered area** needs to be handled following specific procedure. Indeed, the characteristic of covered area the unavailability of GNSS signals, so that the only way to maintain a position estimate is the use of the inertial navigation information.

Consequently, the performance specification is expressed as follows:

- Test scenario: the terminal enters a covered area (loss of GNSS signals), with a perfect position estimate at the beginning of the test.
- Use case: two use cases are successively considered, one dedicated to gyrometry accuracy (speed is constant) the other to accelerometry accuracy (straight trajectory). They are defined in figure 23.

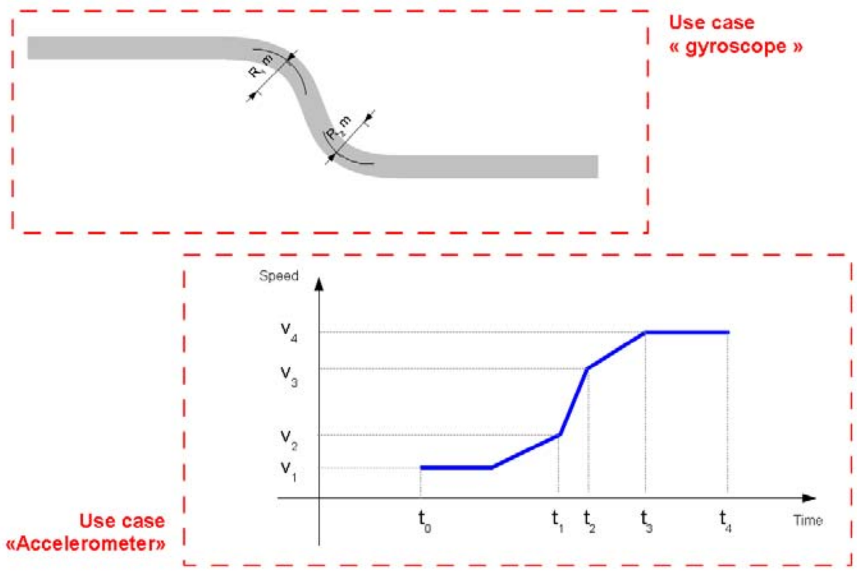


Figure 23: Use case for horizontal accuracy in covered area

- Each use case lasts 60 s.
- At the end of each test, the positioning error has to be below 10 m (TBC).

6.3.2 Authentication

As indicated in clause 5.2.2 Position authentication, authentication of the reported position is required any time fraud is motivated. The performance of an authentication mechanism is measured as:

- the probability to declare the position authentic whereas the terminal is spoofed (mis-detection probability);
- the probability to declare the position fake (i.e. frauded) whereas it is authentic (false alarm probability).

The minimum performance specification is split in two categories:

- position computation for which a GNSS encrypted signal is used.
  In that case, the authentication mechanism is enabled and usually described by the GNSS Signal-in-Space description. For the moment, it is assumed that a perfect fraud detection is achievable with this type of signals, and focus on the second category of performance.

- position computation for which no GNSS encrypted signal is used.
  In that case, authentication information is an added value compare to the basic positioning enabled through GNSS. It is mostly related to the spoofing detection. Description of available mechanisms to implement authentication is given in clause 5.2.2 Position authentication.
  To date, only type 2 receivers have the possibility to support position authentication (i.e. GNSS receiver spoofing).

In order to measure the authentication performance, the operational environment alone (i.e. SV elevation angle, multipath and interference condition, signal attenuation and user dynamic) is not enough. A **threat model** needs to be designed to complete the test case.

The following scenario in figure 24 is a typical use case often used to challenge authentication critical systems.

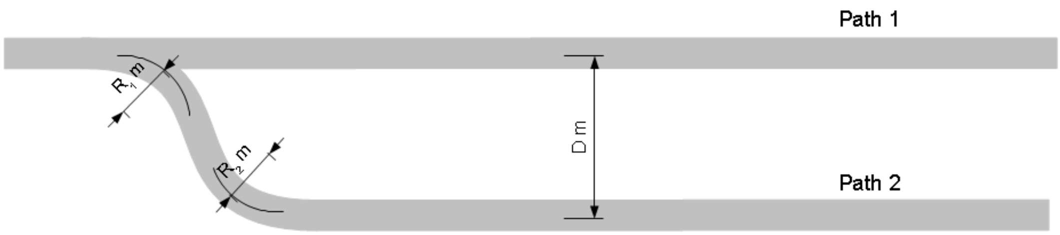


Figure 24: Authentication performance threat model

The use case is as follows:

- charging road is path 1;
- path 2 is free of charge;
- values of R1, R2 and D are respectively **10 m, 10 m and 20 m**, all TBC.
- Mis-detection performance measurement:
  - GNSS RF signals are preliminarily recorded while terminal follows path 2;
  - RF signals are then replayed into GNSS receiver antenna while terminal is using path 1;
  - Authentication function is in charge of identifying the GNSS receiver spoofing.
- False alarm detection measurement:
  - Terminal follows path 1, with no specific spoofing;
  - Authentication function should not falsely declare the receiver spoofed.

The above threat model has to be considered in addition to terminal operational environment. In other words, the proposed road lay out can be considered in any of the operational environments (open area, urban area, etc.).

Based on this scenario, it is possible to derive minimum performance in terms of mis-detection and false alarm. The determination of these performance is proposed to be tackled in the frame of the standardization actions listed in clause 7 Possible standardization action plan and priorities.

6.3.3 Protection Level

As briefly introduced in clause 5.2.4 Position integrity, many application for which the concept of position reliability is a key features adopted the concept of protection level. In the case of 2D positioning (HPL for Horizontal Protection Level) is a smallest distance expected to bound the 2D positioning error, at any time.

As previously reminded, the determination of HPL at terminal level depends on the different error budget potentially impacting the user measurements Those contributors can be differentiated in two categories:

- **GNSS System effects**. Best assessment of these effects are provided by SBAS system in real time via accurate indicators (UDRE and GIVE) are provided in real time to the users. If the system is not able to provide accurate enough indicators it will issue an alarm on the parameter at fault.

- **Local effect such as troposphere, multipath, inference**. At civil aviation level, the solution lies in the use of standard models. For other transport applications (road, train), these models do not stand anymore, and the combinations of sensor allow to have an estimate of the various local error components.

In any case, whether it is inherited from civil aviation or developed for new applications, the determination of the terminal HPL highly depends on the algorithmic core implemented on-board the terminal.

Consequently, in order to issue integrity determination performance (HPL) specification, a number of algorithm have been assessed. Table 11 summarizes the achievable performance function of the terminal type considered.

Table 11: Achievable performance function for different terminal types

Terminal type	Figure of merit	Open area	Rural area	Suburban area	Urban area	Covered area	Asymmetric area	Industrial area
Type 1	HPL Availability	99 %	99 %	98 %	98 %	0 %	99 %	95 %
	HPL - 95 %	50 m - TBC	50 m - TBC	100 m - TBC	200 m - TBC	N/A	200 m - TBC	250 m - TBC
	HPL - Max	1 000 m - TBC	1 000 m - TBC	1 000 m - TBC	1 000 m - TBC	N/A	1 000 m - TBC	1 000 m - TBC
	MI	3 %	3 %	3 %	3 %	N/A	3 %	3 %
Type 2	HPL Availability	100 %	100 %	100 %	100 %	100 %	100 %	100 %
	HPL - 95 %	15 m - TBC	15 m - TBC	50 m - TBC	95 m - TBC	Special	95 m - TBC	120 m - TBC
	HPL - Max	150 m - TBC	150 m - TBC	500 m - TBC	500 m - TBC	Special	500 m - TBC	700 m - TBC
	MI	0 %	0 %	0 %	0,50 %	Special	0 %	0,50 %
Type 3	HPL Availability	99 %	99 %	98 %	98 %	0 %	99 %	95 %
	HPL - 95 %	50 m - TBC	50 m - TBC	70 m - TBC	120 m - TBC	N/A	120 m - TBC	150 m - TBC
	HPL - Max	1 000 m - TBC	1 000 m - TBC	700 m - TBC	700 m - TBC	N/A	700 m - TBC	700 m - TBC
	MI	0,5 %	0,5 %	0,5 %	0,5 %	0,5 %	0,5 %	0,5 %

Comments on the HPL performance function of the terminal type:

- For type 1 receivers (GNSS only), no specific mean allows the reasonably decrease the HPL or the mis-integrity risk. This is due to the fact that local effects contributions are not mastered. Available standard algorithms (MOPS, from civil aviation) does not properly adapt to ground transport conditions, so that important margin has to be taken in order to issue HPL, with, in addition, no real addition value on the confidence level associated to this level (→ non negligible MI).

- For type 2 receivers (GNSS + INS), the use of inertial navigation information highly supports the HPL determination. It indeed allows to get an estimate of the local error contributions, and thus issue a more performing and reliable HPL. All hybridization types have been considered (loose, tight, ultra-tight) all providing much improvement compared to type 2 receivers.

- For type 3 receivers (GNSS + smart antenna), the use of smart allows not only to characterize some interference sources, but also the multipath delayed signal power and impact on the GNSS receiver. This is described in clause 5.4.1.1.4 Smart antenna. Such feature thus allows to bound the most significant local error components (MP and EMI), and hence contribute to the determination of valuable HPL.

6.3.4 Interferer localization

This clause is for further study.

6.4 Test principles

Several approaches concerning environment modelling have been reviewed in the previous clauses.

It is now proposed to issue a synthesis.

Four main streams can be identified:

a) Basic models

It is the basic approach, followed in many standardization bodies such as OMA or 3GPP. Basic models are used to specify the standard performance.

Two major advantage of this method are highlighted:

- First of all, in presence of these basic models, receiver performances are very well mastered. It means that the definition of the minimum performance will follow a known path, with limited risks.
- In addition, in the frame of receiver testing, test results interpretation will be much more efficient. It would be therefore more convenient to isolate the weak points of the unit under test.

b) Complex models

This approach consists of using more complex models than the basic ones, aiming at reaching a better representativity of the real life environments.

Thus, with such approach, we can extend the range of real environments covered by the model, event if, in any case, the coverage will be limited (i.e. for a significant range of types of environment, the model will not be relevant).

The main problem with such approach is that the more complex are the chosen models, the sharper is the environment definition. Since the standard will anyhow have to point on a subset of these environments, it will be very hard to enforce them as reference models.

c) RF replay test methods

Such approach is interesting since it proposed a trade-off between:

- the need to be fully representative of real conditions; and
- the compatibility with standards definition: recorded data can be included in the standard specification.

However, a major problem to solve is the definition of performance specification to be included in the MPS. Indeed, as far as artificial models are concerned, the prevision of the receiver performance requirement is more or less achievable. If real data are used, the environment in which data have been collected needs to be **calibrated**. This should allow to determine how challenging the real environment was, and derived the level of performance that needs to be required.

d) Real environment testing

The last considered approach is the test of the devices in actual real conditions. Such approach has similar attributes as the RF replay strategy: calibration of the real environment.

However, including test in real conditions as part of the GNSS MPS is less straight forward than with the RF Replay technique: how should the test procedure be defined, in particular concerning test location?

In order to solve this problem, a possible way forward is inspired from the Global Certification Forum (GCF) methods (GCF maintains an independent certification scheme for mobile phones and wireless devices that are based on 3GPP standards): the concept of **test house**.

For certification purposes, GCF uses test cases developed and verified by a relevant standards body. So-called test houses actually are companies independent from GCF, in charge of validating the test platforms.

If such scheme is applied for the GNSS MPS, we could define specific test houses whose responsibility is to define and calibrate test locations.

This is also valid for RF replay test method.

Figure 25 gives an overview of the above assessment.

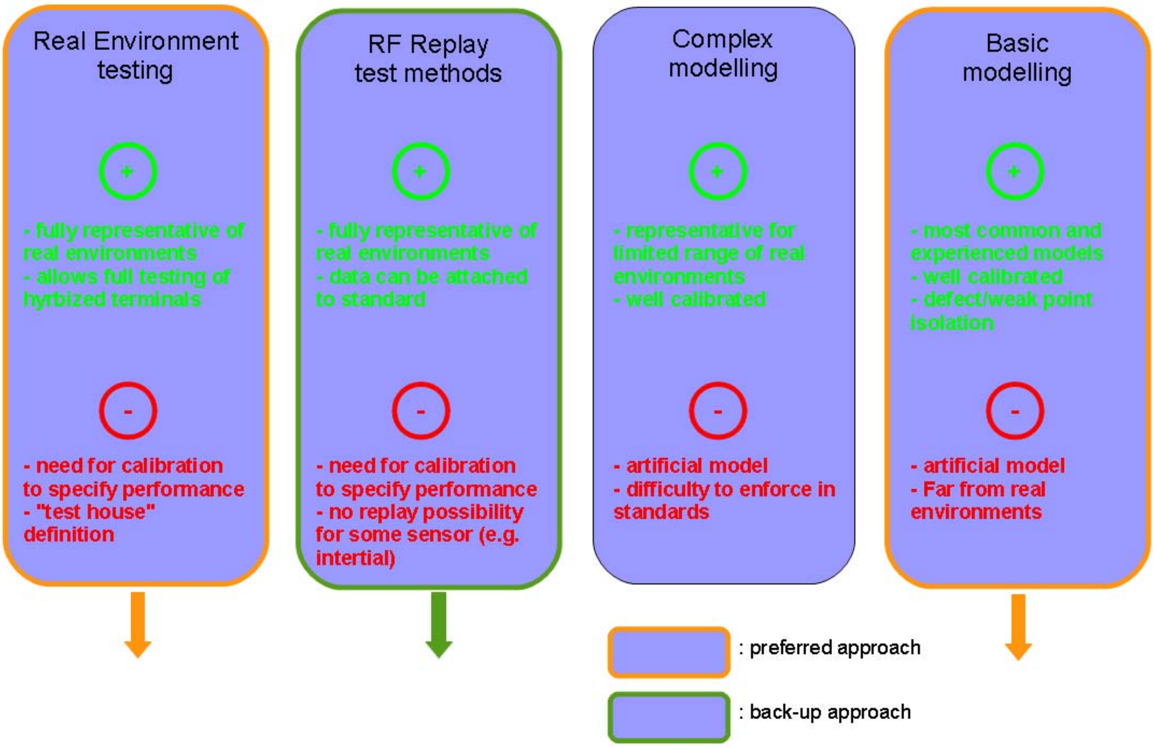


Figure 25: Reference environment definition approach

Based on the above assessment, the following strategy is proposed:

- The best way to test a particular feature or a particular behaviour consists in isolating the phenomenon, and check the response of the receiver to a given stimulus, even if quite simple. In that sense adopting very simple approach for testing appears to be a good approach (cf. 3GPP approach).
- On the other way some phenomenon are very complex, and difficult to isolate. Tests based on real conditions are appropriate for this.

In order to comply with this constraint, it is proposed to push for real life testing for two reasons:

1) It gives the opportunity to push for identified "Test houses" very close to end user conditions.
2) When talking about hybridisation, it is very difficult to replay (and inject) measurements of inertial sensors.

The preferred approach is therefore as highlighted in figure 25.

Still, despite this rationale, the use of RF Replay technique is clearly a very valuable contribution. In particular, from a practical point of view, it is very convenient in the frame of standard definition since test data can be easily attached to the standard.

Consequently, in the short term (before complete test definition of sensors such as intertial is executed) it could be more effective to adopt a "Basic Testing" approach coupled with "RF Replay". This is also highlighted in figure 25, as the "back-up" approach.

7 Possible standardization action plan and priorities

The present document demonstrated both relevancy and achievability of a standardisation initiative addressing the concept of complex location systems used in mass market location based applications. The identified standardisation needs covered mainly the system architecture and performance:

- Based on the functional needs collected from a thorough inventory of the location based application, it provided a number of technical evidences supporting the definition of reference architecture applicable to these location systems. Together with this reference architecture, standard interfaces between the identified system components have also been promoted.
- Furthermore, the application inventory also revealed a wide disparity of performance needs, function of the considered domain. This pushes for the definition at location system level of a minimum performance standard. This is indeed needed to define the achievable performance, function of the technological enablers and operational environment.

Consequently, the following action plan is proposed in order to produce the needed specifications (in clauses 7.1 to 7.3).

7.1 Needed technical specifications

The following specifications are intended to fill the gaps left by existing specifications in order to create a more complete set of specification for the design of locations systems addressing different markets. As such the proposed specification will reference existing specifications as far as possible.

The following technical specification are proposed to be created:

- Technical Specification (TS) for Location System **Reference Architecture**:
  - This TS is intended to define the stage 1 and stage 2 reference architecture for location systems. It will be based on the content of clauses 6.2.1 Stage 1 architecture and 6.2.2 Stage 2 architecture of the present document.
- Technical Specification for Location Data Exchange Protocol:
  - This TS is intended to define the location data exchange protocol at location system level. This in particular cover the handling of the requests received from the application central part, and the protocol to be put in place to ensure to proper information delivery. This aspect is briefly addressed in the part of clause 6.2.2 Stage 2 architecture related to interface number 7.
- Technical Specification for Location System Minimum Performance:
  - This TS is intended to define the location system minimum performance requirements. It will thus:
    - establish the classification of the location system (which includes terminal types and central facility), function of the selected technological enablers (as proposed in clause 5.4 Enabling technologies);
    - define the reference environments applicable to the location system specification (see clause 5.5 Operational environments);
    - introduce and describe the possible "key features" supported by the location system;
    - and finally define the minimum performance requirements applicable, function of the terminal type, operational environment and key feature considered.
- Technical Specification for Test specification, procedure, scenario and data:
  - This TS is intended to provide data needed in order to allow implementation of proper testing of the location systems, in particular regarding the minimum performance and signalling protocols. This TS will be built based on the content of clause 6.4 Test principles.

All of the above TSs are proposed to be produced in the ETSI TC-SES Satellite Communications and Navigation (SCN) working group, which is deemed the relevant specification group to pursue the standardisation work.

Accordingly, work items will be proposed to kick-off the production of these specifications.

As far as implementation plan is concerned, figure 26 illustrates the logical links between the proposed TSs. These interactions indeed drive the implementation plan.

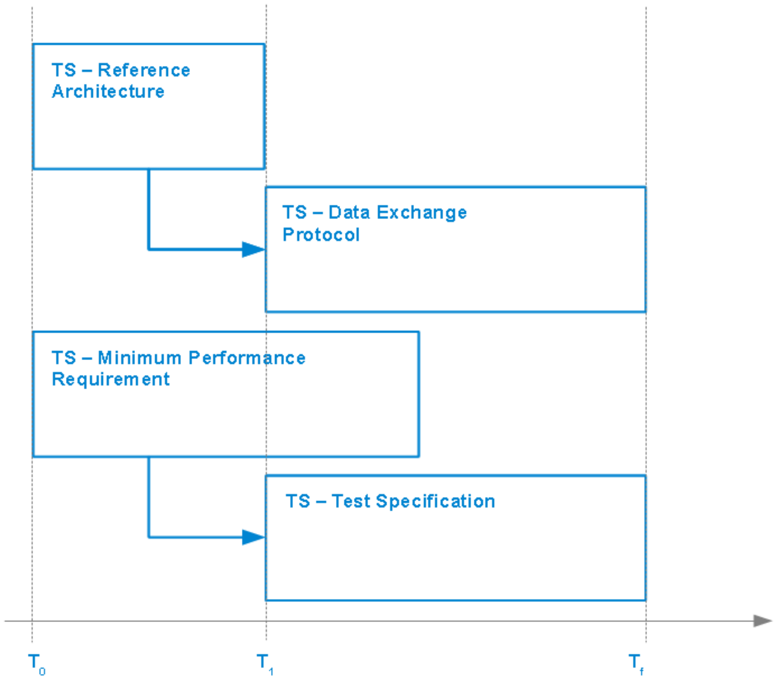


Figure 26: Relationship between planned TSs

Reference architecture and minimum performance requirements are proposed to be addressed first, since they respectively drive the definition of the data exchange protocol and the test specifications.

7.2 Perimeter of first release

The first release of the set of TSs is intended to cover all aspect addressed in the present document.

Further aspects are proposed to be covered in a subsequent release, as presented in the clause 7.3.

7.3 Evolution plan

The following extensions of the standard are proposed:

- Consider additional sub-types of terminal (type 1.x, 2.x):
  - new design (including new sensors);
  - introduce new types of terminal, function of the supported constellations → and therefore possibly issue minimum performance specific for each type of constellation or signal.
- Addition of terrestrial telecommunication sensors data, in particular in the authentication feature → implies to further definition of threat model, including a cell coverage function of the environment selected.
- Evolution of authentication threat model (to reach more complexity), function of authentication mechanism possibly added.
- Use of civil aviation integrity service (EGNOS, WAAS).

History

Document history		
V1.1.1	September 2012	Publication