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Intelligent transport systems (ITS) — Network-based precise positioning infrastructure for land transportation —

Part 2:
Functional requirements and data sets for nomadic devices

Systèmes de transport intelligents — Infrastructure de positionnement précis en réseau pour les transports terrestres —

Partie 2: Exigences fonctionnelles et ensembles de données pour les dispositifs nomades

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Foreword

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This document was prepared by Technical Committee ISO/TC 204, *Intelligent transport systems*.

A list of all parts in the ISO 22086 series can be found on the ISO website.

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Introduction

Lane-level positioning is deemed as a critical function to facilitate emerging applications of intelligent transport systems (ITS) for safety and traffic efficiency. Another critical issue for applications with safety concerns is to guarantee or monitor integrity of the positioning result. Global navigation satellite systems (GNSS) have led the provision of position along with velocity and time information in the ITS domain, but lane-level accuracy cannot be achieved and integrity monitoring functionalities are not supported with commercial low-cost GNSS receivers operating in standalone mode.

The ISO 22086 series deals with standard issues on a nomadic device for lane-level positioning and integrity monitoring with a GNSS-based lane-level positioning system, referred to as network-based precise positioning infrastructure for land transportation (NETPPI-LT). NETPPLI-LT provides additional information to enhance positioning accuracy and to monitor integrity over wireless links.

Intelligent transport systems (ITS) — Network-based precise positioning infrastructure for land transportation —

Part 2: Functional requirements and data sets for nomadic devices

1 Scope

This document specifies the functional requirements of nomadic devices for lane-level positioning and integrity monitoring with the network-based precise positioning infrastructure for land transportation (NETPPI-LT), a lane-level positioning system based on global navigation satellite systems (GNSS) described in ISO/TR 22086-1. This document identifies the GNNS threats to monitor and the errors to remove or mitigate to achieve lane-level accuracy and integrity. It also specifies the data sets to be contained in messages between the nomadic device and the control station providing GNSS correction and integrity information. This specification enables the nomadic device to support lane-level positioning and integrity monitoring. Enabling techniques and methods, which can be different for each provider or vendor, are not addressed in this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/TR 22086-1, *Intelligent transport systems (ITS) — Network based precise positioning infrastructure for land transportation — Part 1: General information and use case definitions*

ETSI EN 302 890-2:2020, *Intelligent transport systems (ITS); Facilities layer function; Part 2: Position and time management (PoTi); Release 2*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/TR 22086-1 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
alert limit
error tolerance not to be exceeded without issuing an alert

3.2
augmentation information
correction and *integrity information* (3.7) for global navigation satellite systems (GNSS) measurements

3.3
auxiliary reference station
reference station within a set of the reference networks, which captures global navigation satellite systems (GNSS) *raw measurements* (3.14) at a known position and sends them to the control stations of the network-based precise positioning infrastructure for land transportation (NETPPI-LT) to produce correction differences of the *range measurements* (3.12) relative to the ones of the *master reference station* (3.8)

3.4
carrier-phase measurement
measure of range between a navigation satellite and a nomadic device or a global navigation satellite systems (GNSS) receiver embedded within the nomadic device, based on the phase measurements of the carrier frequency

Note 1 to entry: Carrier-phase measurement is expressed in metres.

3.5
pseudorange (code) measurement
measure of range between a navigation satellite and a nomadic device or a global navigation satellite systems (GNSS) receiver embedded within the nomadic device, based on the phase delay of the pseudorandom noise code

Note 1 to entry: Pseudorange measurement is expressed in metres.

3.6
correction information
information including *raw measurements* (3.14) of a master or virtual reference station and correction differences for pairs of reference stations to remove common errors in global navigation satellite systems (GNSS) *range measurement* (3.12) of a nomadic device

3.7
integrity information
information used to determine either the occurrence of failures or uncertainties (e.g. one-sigma) in the position domain

3.8
master reference station
reference station within a set of the reference networks, for which *raw measurements* (3.14) and coordinate information are transmitted to a nomadic device via the control stations of the NETPPI-LT

3.9
navigation message
message containing ephemeris data, used to calculate the position of each global navigation satellite systems (GNSS) satellite in orbit, and information on time and status of entire satellites in the constellation

3.10
network RTK
network real-time kinematic
RTK (3.13) technique based on multiple reference stations to support an extended service coverage by provisioning correction differences of the *range measurements* (3.12) for pairs of master and *auxiliary reference stations* (3.3) in addition to *raw measurements* (3.14) of the *master reference station* (3.8)

3.11
protection level
upper bound for the positioning error, which is an instantaneous estimate based on different measurements related to the quality of the received signal, *range measurements* (3.12), and *navigation message* (3.9)

3.12
range measurement
pseudorange and *carrier-phase measurements* (3.4) between a navigation satellite and a nomadic device or a global navigation satellite systems (GNSS) receiver embedded within the nomadic device

3.13
real-time kinematic
RTK
differential global navigation satellite systems (GNSS) technique that provides, in real time, highly accurate positioning for a nomadic device based on *carrier-phase measurements* (3.4), which are corrected by referring *raw measurements* (3.14) of a single reference station

3.14
raw measurement
measurement available in a global navigation satellite systems (GNSS) receiver after the signal processing stage before the positioning stage including *code measurements* (3.5), *carrier-phase measurements* (3.4), *navigation messages* (3.9), and signal quality indicators

4 Abbreviated terms

5G	fifth-generation mobile communications
CCD	code carrier divergence
CS	control station
DMB	digital multimedia broadcasting
DSRC	dedicated short-range communications
FDI	fault detection and isolation
GNSS	global navigation satellite systems
ITS	intelligent transportation system
LTE	long term evolution
MQM	measurement quality monitoring
ND	nomadic device
NRTK	network real-time kinematic
NETPPI-LT	network based precise positioning infrastructure for land transportation
OSR	observation space representation
PL	protection level
PoTi	position and time management
PPP	precise point positioning
PPP-RTK	precise point positioning-real time kinematic
PRN	pseudorandom noise
RF	radio frequency
RTCM	radio technical commission for maritime services
RTK	real-time kinematic
SSR	state space representation

WAVE	wireless access for vehicular environment
YE-TE	yesterday-minus-today ephemeris

5 Functional requirements

5.1 Overview

This document conforms to the GNSS-based positioning terminal model specified in EN 16803-1 for the reference model of nomadic devices in which the output to safety-related applications includes the positioning result and the protection level. Such output is used for providing warnings to the users or the systems and services based on GNSS when exceeding a given alert limit, i.e. the largest positioning error acceptable for the operation.

The nomadic device shall support the PoTi (position and time management) service at the facilities layer specified in accordance with ETSI EN 302 890-2. The functions described in this document are implemented as part of the position augmentation, which is a function of the PoTi entity.

The nomadic device performs a series of functions to ensure lane-level accuracy and integrity with the NETPPI-LT. Its functional architecture is illustrated in Figure 1. The nomadic device can include multiple positioning modules in addition to GNSS and can integrate all the data from the modules for positioning as specified in EN 16803-1. As those methods are beyond the scope of this document, relevant architectures are not depicted in Figure 1.

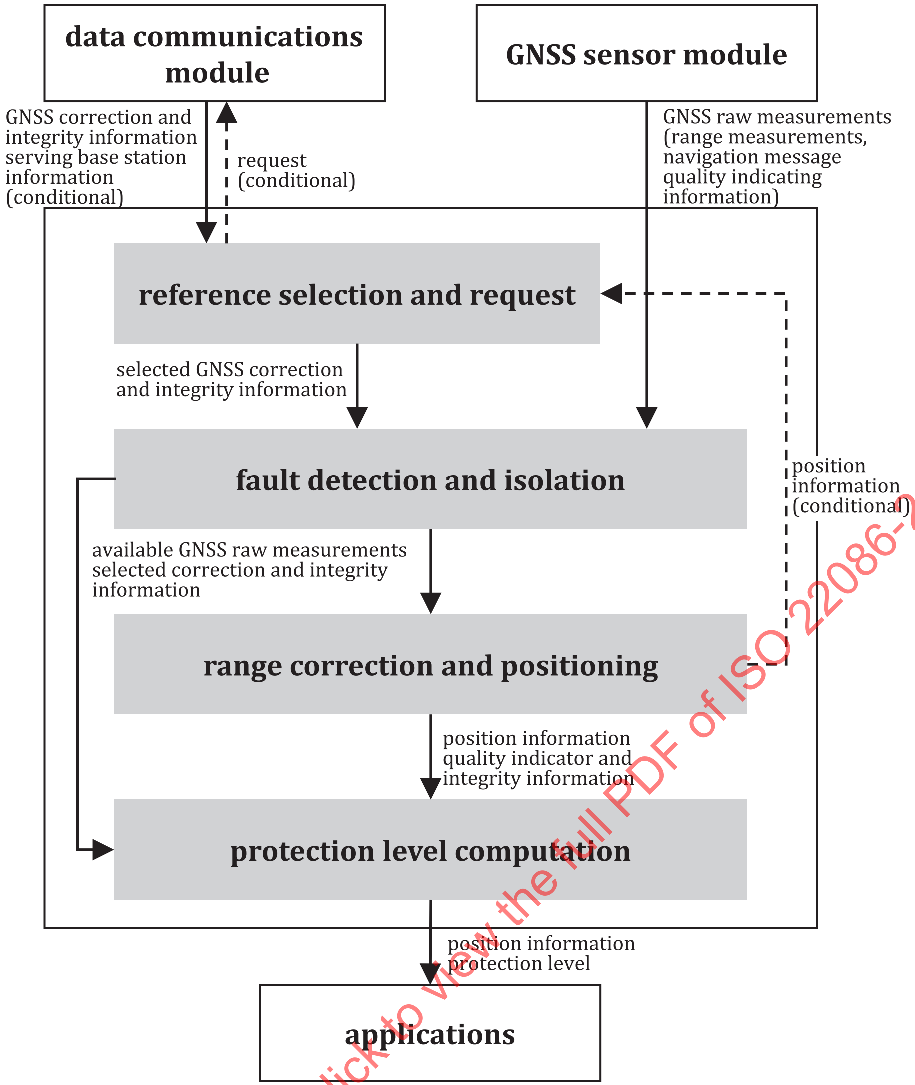

Figure 1 — Functional architecture for lane-level positioning and integrity monitoring

Each function for lane-level positioning and integrity monitoring on the nomadic device is described as follows:

— reference network selection and request;

— fault detection and isolation;

— range correction and positioning;

— protection level computation.

To support these functions, the GNSS receiver equipped on the nomadic device shall provide the following measurements:

— GNSS type;

— satellite PRN number;

— code and carrier-phase measurements;

— navigation message;

— carrier-to-noise ratio or signal-to-noise ratio of the signal;

— lock time;

— loss of lock indicator.

5.2 Reference network selection and request

The nomadic device shall implement the reference network selection and request, according to data provisioning, either on-demand (unicasting) or broadcasting manners. With the on-demand manner, the control station provides the GNSS correction information and integrity information as the response to the request of the nomadic device. The on-demand manner is preferable for data channels of mobile communications (e.g. LTE, 5G, WAVE, DSRC). The broadcasting manner is a typical configuration in which the control station's data is provided over one-way links (e.g. DMB, satellite broadcasting as specified in ISO 18197) according to the scheduled plans.

Table 1 defines the processing flows and data requirements for the reference network selection and request.

Table 1 — Processing flows and data requirements for reference selection and request

Processing flows			From	To	Data requirements
On-demand (unicasting)	a)	ND requests CS to provide the reference network information, such as reference network configurations, status, identification numbers and supporting GNSS, before requesting specific reference information.	ND	CS	See 6.2
	b)	ND updates the reference network information received from CS as the response to the ND's request.	CS	ND	See 6.3
	c)	ND selects desired reference networks for correction and requests CS to transmit the corresponding information.[a]	ND	CS	See 6.4
	d)	ND receives the information of the desired reference networks as the response to the ND's request.	CS	ND	See 6.5
Broadcasting	a)	ND updates the reference network information periodically received from CS.	CS	ND	See 6.3
	b)	ND receives the information of all reference networks and selects the desired reference networks for correction and monitoring.	CS	ND	See 6.5
[a] The request should be made if the desired reference networks have changed.					

5.3 Fault detection and isolation

The nomadic device is required to properly detect and filter out the GNSS satellites under threat of causing unacceptably large errors in range measurements. GNSS threats are described in described in Table 2.

Table 2 — GNSS threats

Threats		Description
GNSS satellite anomalies		The satellite signals are corrupted by satellite ephemeris error, clock error, and signal deformation.
Atmospheric anomalies		The satellite signals are refracted or diffracted during propagation over ionosphere and troposphere by unexpectedly anomalous activities (e.g. solar flares, corona mass ejection, geomagnetic storms).
RF interference	Intentional	The satellite signals are either drowned out or deceived by locally-generated RF signals (e.g. jamming, spoofing).
	Unintentional	The satellite signals are interfered with by nearby RF transmitters or by reflections (multipath) from nearby structures.
Facility failures		The NETPPI-LT information (GNSS correction and integrity) is corrupted, lost and delayed during data generation and transmission.

Among the GNSS threats in Table 2, GNSS satellite anomalies, atmospheric anomalies, intentional RF interference, and facility failures shall be monitored by the NETPPI-LT. Those satellites considered to be faulty by the NETPPI-LT shall be notified to the nomadic device. Examples of GNSS fault detection are described in Annex A.

The nomadic device can also detect faulty satellites affected by GNSS satellite anomalies, atmospheric anomalies, intentional and unintentional RF interferences based on GNSS measurements obtained by the nomadic device during a specific period. The GNSS measurements for detecting such faults shall include navigation message, code measurement, carrier-phase measurement and signal strength of each satellite. The nomadic device shall monitor the NETPPI-LT information loss and delay, which is part of the facility failures, by referring message numbers and time information contained in the NETPPI-LT message transmitted by the control station.

The nomadic device is required to output information of available satellites for the input of the range correction and positioning function.

5.4 Range correction and positioning

At every epoch, each nomadic device takes two types of range measurements from each satellite:

a) code measurements [see Formula (1)];

b) carrier-phase measurements [see Formula (2)].

These are typically defined as follows:

$$\rho_{\mathrm{u}}^{\mathrm{k}} = r_{\mathrm{u}}^{\mathrm{k}} + E_{\mathrm{u}}^{\mathrm{k}} + c\left(t^{\mathrm{k}} - t_{\mathrm{u}}\right) + T_{\mathrm{u}}^{\mathrm{k}} + I_{\mathrm{u}}^{\mathrm{k}} + v_{\mathrm{u}}^{\mathrm{k}} \quad (1)$$

$$\phi_{\mathrm{u}}^{\mathrm{k}} = r_{\mathrm{u}}^{\mathrm{k}} + E_{\mathrm{u}}^{\mathrm{k}} + c\left(t^{\mathrm{k}} - t_{\mathrm{u}}\right) + T_{\mathrm{u}}^{\mathrm{k}} - I_{\mathrm{u}}^{\mathrm{k}} + \lambda N_{\mathrm{u}}^{\mathrm{k}} + w_{\mathrm{u}}^{\mathrm{k}} \quad (2)$$

where

subscript u denotes the receiver;

superscript k denotes the satellite;

$\rho_{\mathrm{u}}^{\mathrm{k}}$ is the pseudorange (code) measurement, expressed in metres (m);

$\phi_{\mathrm{u}}^{\mathrm{k}}$ is the carrier-phase measurement, expressed in metres (m);

$r_{\mathrm{u}}^{\mathrm{k}}$ is the true range, expressed in metres (m);

$E_{\mathrm{u}}^{\mathrm{k}}$ is the satellite orbit error, expressed in metres (m);

c is the speed of light, which is 299 792 458 metres per second (m/s);

t^{k} is the satellite clock bias, expressed in seconds (s);

t_{u} is the receiver clock bias, expressed in seconds (s);

$T_{\mathrm{u}}^{\mathrm{k}}$ is the tropospheric delay, expressed in metres (m);

$I_{\mathrm{u}}^{\mathrm{k}}$ is the ionospheric delay, expressed in metres (m);

λ is the wavelength of satellite signal, which is $19{,}05\times10^{-2}$ metres (m) for L1 frequency;

$N_{\mathrm{u}}^{\mathrm{k}}$ is the integer ambiguity;

$v_{\mathrm{u}}^{\mathrm{k}}$ is the code measurement noise including remaining errors (e.g. multipath), expressed in metres (m);

$w_{\mathrm{u}}^{\mathrm{k}}$ is the carrier-phase measurement noise including remaining errors, expressed in metres (m).

The nomadic device shall perform precise positioning augmentation for lane-level positioning. According to ISO 24246, such augmentation techniques are classified into original and enhanced techniques as described in Table 3.

Table 3 — Precise positioning augmentation and correction data defined in ISO 24246

Method	**Carrier-phased GNSS**	
Correction	**OSR**	**SSR**
Original technique	RTK — Pseudorange — Carrier-phase At a reference station	PPP — Satellite clock correction — Satellite orbit correction — Signal bias — Integrity information
Enhanced technique	Network RTK — Pseudorange — Carrier-phase At not only physical but also non-physical reference stations	PPP-RTK — Satellite clock correction — Satellite orbit correction — Signal bias (code) — Signal bias (carrier-phase) — Ionospheric correction — Tropospheric correction — Integrity information

5.5 Protection level computation

The protection level shall be computed and produced along with the positioning result. The following data can be used for computing the protection level:

— one-sigma on GNSS receiver-instigated noise under a given hypothesis;

— bias and one-sigma on errors in corrections under a given hypothesis.

A hypothesis includes both normal and faulted conditions. The computed PL can be used at the application level for determining whether the positioning result achieves a given accuracy required for the applications. If the PL exceeds the alert limit of an application, the positioning result is said not to guarantee the required accuracy. The concept of protection level computation is described in Annex B.

6 Message set definitions

6.1 General

The messages described in 6.2 to 6.5 can be used between the nomadic device and the control station(s) to request or to receive relevant information for lane-level positioning and integrity monitoring. The messages may be provided via either standardized formats (e.g. RTCM 10403.3) or non-standardized formats.

6.2 Request network information

The nomadic device intended to receive reference stations/networks information is required to communicate this intention to the control station(s) by way of a message containing:

a) message information, including

— message generation time and time reference system, and

— message type;

b) update information, including

— last update information (e.g. update date, version) on the reference stations/networks.

6.3 Receive network information

The control station(s), either upon the request of the nomadic device or upon the scheduled plan, is required to transmit to the nomadic device a message containing:

a) message information, including

— message generation time and time reference system, and

— message type;

b) reference station information, including

— identification of reference stations,

— status of reference stations,

— coordinates (position) of reference stations and coordinate reference system, and

— supporting GNSS by reference stations;

c) network configuration information, including

— identification of reference networks,

— status of reference networks,

— number of reference stations and their identification in each reference network, and

— augmentation techniques supported by each reference network.

6.4 Request augmentation information

The nomadic device intended to receive augmentation (correction and integrity) is required to communicate this intention to the control station by way of a message containing:

a) message information, including

— message generation time and time reference system, and

— message type;

b) request information, including

— identification of desired reference stations/networks (conditional for RTK, NRTK, and PPP-RTK),

— GNSS types and augmentation techniques to be supported, and

— data transmission rate.

6.5 Receive augmentation information

The control station(s), either upon the request of the nomadic device or upon the scheduled plan, is required to transmit to the nomadic device this message containing:

a) message information, including

— message generation time and time reference system, and

— message type;

b) reference network information (conditional for RTK, NRTK, and PPP-RTK), including

— identification of reference stations/networks and their status, and

— master and auxiliary indicator for a reference station in each reference network;

c) augmentation information, including

— GNSS type and identification of each satellite,

— status of each satellite,

— issue of ephemeris date,

— set of code and carrier-phase measurements for GNSS satellites at reference stations/networks,

— set of corrections specified in Table 3 (conditional for PPP and PPP-RTK),

— one-sigma on GNSS receiver-instigated noise under a given hypothesis, and

— bias and one-sigma on errors in corrections under a given hypothesis.

Annex A
(informative)

Examples of GNSS fault detection

A.1 Overview

GNSS threats described in Table 2 cause unacceptably large errors in range measurements. For reasons of safety, the NETPPI-LT control station is required to alert nomadic devices when GNSS threats occur. This is done by detecting faulty range measurements with different monitoring methods relevant to each fault mode and by issuing fault alerts to nomadic devices. This annex introduces well-known methods of detecting and mitigating two major GNSS threats: satellite-related and ionospheric-related faults. These fault types are used as examples.

A.2 GNSS satellite fault detection methods

A.2.1 Satellite clock fault

Satellite clock instability in broadcast satellite signals has been the most common failure affecting GPS satellites. It commonly manifests itself as rapid and unpredictable clock dynamics that produce significant range measurement errors relative to clock corrections in satellite navigation data. For example, a clock event, which occurred on 1988-03-10 on SVN 27, induces an unacceptably large error larger than 15 m with a high range change rate.[5]

The rapid varying signatures in range measurements, resulting from the transient between normal and unstable clock behaviour, is typically easy to detect with the well-known method called measurement quality monitoring (MQM) as defined in Reference [6]. MQM consists of three sub-monitors: the receiver lock check, the carrier acceleration-ramp-step-test, and the carrier-smoothed code innovation test. A series of these three sub-monitors tests and confirms the consistency of code and carrier-phase measurements over time to detect sudden steps or any other impulsive errors in range measurements due to GNSS clock faults.

A.2.2 Satellite ephemeris fault

A situation where the actual satellite location in orbit is significantly different from the one derived from the broadcast ephemeris data is defined as a satellite ephemeris fault. The satellite ephemeris fault can be classified into two types, based on whether or not the fault is associated with a satellite manoeuvre. For the former (Type A), the satellite manoeuvres away from its broadcast orbit, or the broadcast orbit is not properly updated after a planned manoeuvre take place. For the latter (Type B), no satellite manoeuvre occurs, but a significantly erroneous parameter somehow enters the set of broadcast data.

A precise ephemeris validation method called the yesterday-minus-today ephemeris (YE-TE) test can easily detect Type A events by confirming the consistency between the broadcast ephemeris and the most recently validated ephemeris.[6] On the other hand, Type B events are less likely to be detected since there is no validated ephemeris to be compared right after the satellite manoeuvre occurs. One possible method capable of detecting Type B events is to monitor the measurement correction derived from the broadcast ephemeris and the reference station.[6]

A.3 Ionosphere-related fault detection method

The signal delay affecting GNSS code and carrier-phase measurements due to the ionosphere is the greatest challenge to be mitigated among GNSS faults. Under normal ionosphere condition, ionosphere changes very smoothly over a large area so ionosphere-induced errors are well-behaved and relatively easy to be corrected. However, under unusual ionosphere condition, the electron density is enhanced dramatically and