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GUIDELINE

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GNSS SATELLITE-BASED PRECISE POINT POSITIONING (PPP) MARITIME SERVICE

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Revisions to this document are to be noted in the table prior to the issue of a revised document. The latest edition of the Guideline is the only version in force unless the Guideline is explicitly revoked by the Council.

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1. BACKGROUND

Global Navigation Satellite Systems (GNSS) have become the primary means of obtaining Position, Navigation, and Timing (PNT) information at sea, and most vessels are equipped with GNSS receivers in accordance with SOLAS requirements [1].

Within satellite-based high-precision maritime services, Precise Point Positioning (PPP) is a global absolute positioning technique that combines multi-frequency GNSS carrier-phase measurements with correction data, including satellite orbit, clock, and signal biases, as well as atmospheric effects such as ionospheric and tropospheric delays. These corrections are generated from global or regional networks of GNSS monitoring stations and are delivered to users via satellite or internet links. By applying these corrections, PPP enables decimetre- to centimetre-level positioning accuracy without requiring nearby reference stations.

The performance of PPP depends on the accuracy and continuity of correction data, satellite visibility and geometry, and the duration of continuous observations. Although PPP can achieve high accuracy, it typically requires a convergence period to resolve local errors such as atmospheric effects, multipath, and satellite geometry [2]. The convergence time and final accuracy are largely influenced by the quality of corrections and receiver processing strategies.

PPP can be implemented in two main modes: post-processed and real-time. Post-processed PPP generally provides higher accuracy, while real-time PPP enables immediate positioning but relies on continuous transmission of correction data. A key feature of PPP is the estimation of carrier-phase ambiguities. When additional corrections such as satellite phase biases and atmospheric information are provided, ambiguity resolution can be achieved, significantly improving convergence time and positioning accuracy. This enhanced approach is commonly referred to as PPP-RTK, which can deliver near-instantaneous convergence and centimetre-level performance.

Satellite-based PPP services broadcast correction data through GNSS signals, enabling wide-area coverage, uniform accuracy, and reduced dependence on dense ground infrastructure. These characteristics make PPP particularly suitable for maritime applications such as autonomous berthing, channel surveying, dredging, and cargo operations, where high-precision positioning is essential. Satellite-based PPP services are expected to play an increasing role in future resilient PNT solutions for maritime navigation.

2. OBJECTIVE

The objective of this Guideline is to provide guidance on the use of satellite-based PPP services for maritime navigation. This document defines the characteristics, performance considerations, and operational aspects of satellite-based PPP services relevant to maritime authorities, service providers, and end users.

3. DEFINITIONS

This section contains core terms and definitions to assist understanding of the document content [3]. Other terms and definitions can be found in the International Dictionary of Marine Aids to Navigation.

- PPP (Precise Point Positioning): A method for global absolute positioning that combines multi-frequency GNSS phase measurements with error corrections (satellite orbit, clock, signal biases, and atmospheric effects) to achieve decimetre/centimetre-level accuracy without local reference stations.
- Satellite-based PPP service: A PPP service in which correction data are broadcast via satellite signals in space, enabling global or wide-area user access without reliance on terrestrial communication infrastructure.
- PPP-RTK (Precise Point Positioning-Real Time Kinematic): A PPP implementation that provides accurate ionospheric and tropospheric corrections, enabling full atmospheric error correction, near-instantaneous convergence, and centimetre-level accuracy.

- Convergence time: The time required for a PPP solution to reach its specified performance level after initialization.
- Integrity: The ability of a system to provide timely warnings to users when the system should not be used for navigation.
- SiS (Signal in Space): The GNSS signal transmitted from satellites to users, including navigation data and augmentation information.

4. IMO RESOLUTION A.1046(27) AND A.915(22) REFERENCE REQUIREMENTS

IMO Resolution A.1046(27) established the requirements that a radionavigation system needs to be recognized by IMO as a component of the Worldwide Radionavigation System (WWRNS)[4]. These requirements are considered to be the prerequisite reference requirements for the implementation of PPP Service in maritime navigation. Moreover, considering the strong scenario-specific coupling between PPP's precision services and maritime applications and operations, IMO Resolution A.915(22) operational requirements published in 2001 are considered to be the appropriate reference requirements for the implementation of GNSS following GPS and GLONASS[5].

4.1. IMO RESOLUTION A.1046(27) REQUIREMENTS

As of 2026, IMO has recognized six GNSS systems (GPS, GLONASS, BDS, Galileo, IRNSS, QZSS) as the WWRNS elements in ocean waters. As one potential capability of the GNSS elements recognized by IMO WWRNS, such as BDS, Galileo, QZSS, and so on, the GNSS satellite-based PPP service should comply with the responsibilities of Governments or organizations and meet the operational requirements. Meanwhile, with the sub-decimeter precise positioning capability of GNSS satellite-based PPP service, the recognized WWRNS can achieve the performance levels required in IMO Resolution A.1046(27) for coastal areas and harbour approaches.

IMO Resolution A.1046(27) establishes the operational requirements that a radionavigation system shall fulfill, which are summarized in the table below:

Table 1 IMO Resolution A.1046(27) operational requirements

	Ocean waters	Harbour entrance, harbour approach, and coastal waters
Accuracy (95%)	100 m	10 m
System Integrity (Time to alarm)	As soon as practicable by Maritime Safety Information	Within 10s
Signal Availability	99.8%	99.8%
Continuity	N/A	99.97%(over 15 min)

Moreover, IMO Resolution A.1046(27) requires that governments or organizations owning and operating the recognized radionavigation systems should consider the following user requirements for reference:

- The government or organization providing and operating the system has stated formally that the system is operational and available for use by merchant shipping.
- The continued provision of the service is assured.
- The system is able to provide position information within the declared coverage area with a performance not less than that established in the present resolution.

- Adequate arrangements have been made for the publication of the characteristics and parameters of the system and of its status.
- Adequate arrangements have been made to protect the safety of navigation should it be necessary to introduce changes in the characteristics or parameters of the system that could adversely affect the performance of ship-borne receiver equipment.

4.2. IMO RESOLUTION A.915(22) REQUIREMENTS

IMO Resolution A.915(22) established general requirements, operational requirements, institutional requirements, and transitional requirements for the WWRNS GNSS elements after 2001. The requirements can be summarized below:

- A future GNSS should primarily serve the operational user requirements for general navigation. This includes navigation in harbour entrances and approaches, and other waters in which navigation is restricted.
- A future GNSS should have the operational and institutional capability to meet additional area-specific requirements through local augmentation, if this capability cannot be provided otherwise. Augmentation provisions should be harmonized worldwide to avoid the need for carrying more than one ship-borne receiver or other devices.
- A regional satellite navigation system that is fully operational may be recognized as a component of the WWRNS.
- Therefore, the administration may consider whether the above requirements should be fulfilled and documented by the GNSS satellite-based PPP service provider. This could be achieved by using the appropriate IALA-recommended methods.

The list of service parameters required for a complete characterization of a GNSS satellite-based PPP service is derived from the list in IMO Resolution A.915(22) and IALA Guideline 1127, shown in Table 2.

Table 2 IMO Resolution A.915(22) service requirements

	System-level parameters					Service level parameters			
	Accuracy		Integrity						
	Horizontal(m)	Vertical(m)	Alert limit (m)	Time to alarm 2 (seconds)	Integrity risk (per 3 hours)	Availability % per 30 days	Continuity % over 3hours	Coverage	Fix interval2 (seconds)
Operations	**Relative accuracy**								
tugs and pushers	1		2.5	10	10^-5	99.8	99.97	Local	1
icebreakers	1		2.5	10	10^-5	99.8	99.97	Local	1
	Absolute accuracy								
automatic docking	0.1		0.25	10	10^-5	99.8	99.97	Local	1
Hydrography	1-2	0.1	2.5-5	10	10^-5	99.8	N/A	Regional	1
Marine engineering, construction, maintenance and management									
dredging	0.1	0.1	0.25	10	10^-5	99.8	N/A	Local	1
cable and pipeline laying	1	N/A	2.5	10	10^-5	99.8	N/A	Regional	1
construction works	0.1	0.1	0.25	10	10^-5	99.8	N/A	Local	1
Aids to navigation management	1	N/A	2.5	10	10^-5	99.8	N/A	Regional	1
Port operations	**Absolute accuracy**								
local VTS	1	N/A	2.5	10	10^-5	99.8	N/A	Local	1
container/cargo management	1	1	2.5	10	10^-5	99.8	N/A	Local	1
law enforcement	1	1	2.5	10	10^-5	99.8	N/A	Local	1

	System-level parameters					Service level parameters			
	Accuracy		Integrity			Availability % per 30 days	Continuity % over 3hours	Coverage	Fix interval2 (seconds)
	Horizontal(m)	Vertical(m)	Alert limit (m)	Time to alarm 2 (seconds)	Integrity risk (per 3 hours)				
cargo handling	0.1	0.1	0.25	1	10^-5	99.8	N/A	Local	1
Casualty analysis	Predictable accuracy								
port approach and restricted waters	1	N/A	2.5	10	10^-5	99.8	N/A	Regional	1
Offshore exploration and exploitation	Absolute accuracy								
exploration	1	N/A	2.5	10	10^-5	99.8	N/A	Regional	1
appraisal drilling	1	N/A	2.5	10	10^-5	99.8	N/A	Regional	1
field development	1	N/A	2.5	10	10^-5	99.8	N/A	Regional	1
support for production	1	N/A^2	2.5	10	10^-5	99.8	N/A	Regional	1
post-production	1	N/A^2	2.5	10	10^-5	99.8	N/A	Regional	1

5. GNSS SATELLITE-BASED PPP SERVICE

The main elements of a basic GNSS satellite-based PPP service architecture are usually as follows:

- Space segment: Includes the satellites with payloads aimed to transmit the corrections to the GNSS core constellations.
- Ground segment: Includes all the ground elements which provide the PPP navigation messages.
  - master control station (MCS)
  - uplink stations (ULS)
  - monitoring stations (MS)
- User segment: Includes the user equipment needed to receive and use the GNSS high-accuracy PPP service information.

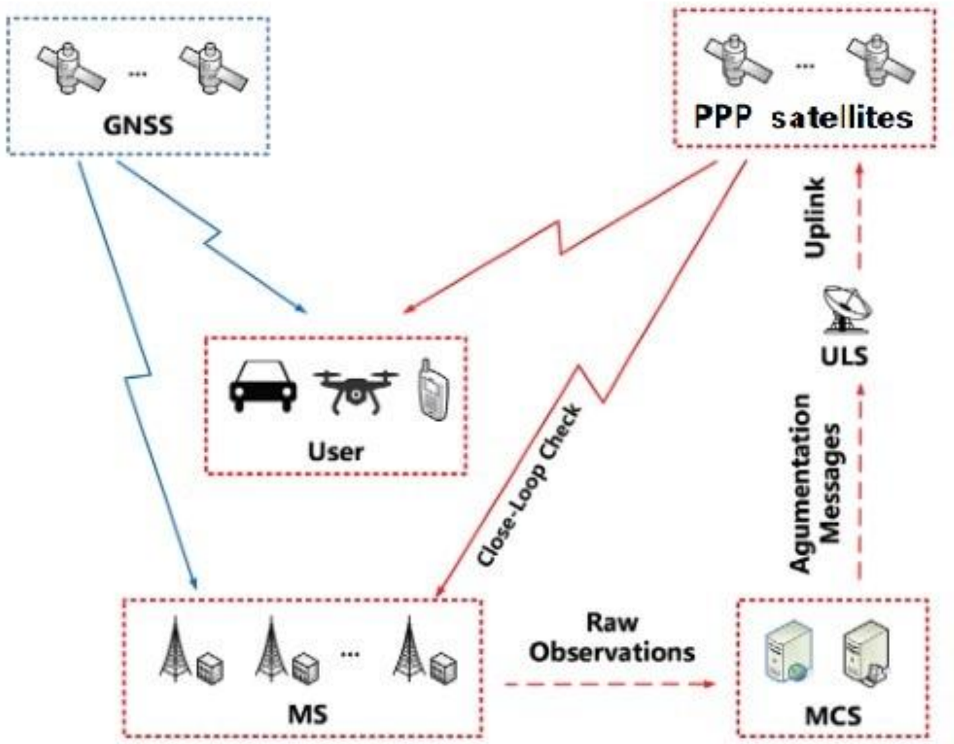

Figure 1 Basic GNSS satellite-based PPP service architecture

Satellite-based PPP services typically have the following characteristics:

- Global or wide-area coverage.
- Broadcast delivery via satellite signals in space.
- Independence from terrestrial communication infrastructure.
- Requirement for a convergence period.

PPP services require a convergence period after initialisation before the target positioning performance is achieved.

5.1. EXISTING AND PLANNED GNSS SATELLITE-BASED PPP SYSTEMS

The current institutional service providers of PPP/PPP-RTK are Australia/New Zealand (SouthPAN), China (BDS), the EU (Galileo), Korea (KPS), Japan (QZSS), and Russia (GLONASS) . At the time of writing this report, only Japan, China, and the EU provide an operational service: QZSS CLAS, BDS PPP, and Galileo HAS, respectively. Australia/New Zealand is also offering an early open service of PPP via SouthPAN on L5. Russia is offering a ground-based experimental service and developing its satellite-based service. Finally, Korea is developing an open PPP-RTK service via KPS. All providers offer PPP. The existing and Planned GNSS satellite-based PPP service and their status are shown in Table 3 below:

Table 3 The existing and planned GNSS satellite-based PPP systems

Country/ Region	GNSS satellite-based PPP system	Organization in charge	Coverage area	Broadcast Signals	Status	GNSS Augmented	CHARGE /FREE
China[5]	BDS PPP B2b	China Satellite Navigation Office	Asian-Pacific Area	PPP-B2b	Operational	GPS BDS GALILEO GLONASS	free
Europe [10-13]	Galileo HAS	EUSPA	SL1： GLOBAL SL2： EUROPEAN AREA	E6-b	Operational (Initial Service)	GPS Galileo	free
Japan [15,16]	CLAS QZSS MADOCA-PPP	Cabinet Office of Japanese Government	Asia and Oceania Area	L6-d L6-e	Operational	QZSS BDS GPS GALILEO GLONASS	free
Australia and New Zealand [7][8]	PPP via SouthPAN (PVS)	Geoscience Australia and Toitū Te Whenua Land Information New Zealand	Australian and New Zealand	L5 (now) L5-b (future)	Operational (Initial Service: OS-PVS-IOC; Full Service: OS-PVS-FOC)	GPS Galileo	free
Korea [14]	KPS POINT	Ministry of Oceans and Fisheries, and Korea Aerospace Administration	Republic of Korea	L6	Ground-based (Operational)Satellite-based (future)	GPS Galileo KPS	free
Russia [17][18]	GLONASS PPP	ROSCOSMOS, State Space Corporation, Russian Federation	Russian Federation Global(future)	L3SVO	Ground-based experiment Satellite-based (future)	GLONASS GPS Galileo BDS	N/A

5.2. CORRECTION PARAMETERS

PPP Messages are synchronized with their own system time reference through a preamble or synchronization pattern transmitted regularly, as is the case for most GNSS signals. The satellite corrections are linked to the corrected broadcast messages through the broadcast IODs, and satellite ID. Error detection and/or correction codes are added in all messages.

Regarding satellite corrections, all corrections are provided for satellite broadcast orbits and clocks. Code biases between multiple signals are provided, where GPS L1C/A is one of them in all cases. Other corrected signals include L5/E5a, E5b/B2, L2C/L2OF and E6. Phase biases are provided by QZSS and will be provided by Galileo and GLONASS. Note that biases are closely related to satellite antenna phase centers. Usually, PPP/PPP-RTK service providers will align their satellite clock products with the satellite center of mass (Ref. CoM) or the satellite antenna phase centers (Ref. APC). Which reference point, CoM or APC, to be used will lead to different code/phase bias corrections, and they are totally incompatible. Therefore, the observations used for code/phase bias estimation will be corrected by the APC corrections, in order to reconcile the signal bias to a frequency-independent reference point that is consistent across the server side and the user side. This has long been a common practice in bias estimation processes using geometry-related observations (e.g., for ionosphere-free phase bias), but the consensus on this reference point was not clearly established until recently for bias estimation processes using geometry-free observations (e.g., for MW phase bias and differential code bias). The APC issue should be considered when accounting for the interoperability of PPP bias products.

Regarding atmospheric corrections, ionosphere corrections are already provided by QZSS through STEC (Slant Total Electron Content) and will be provided by Galileo HAS through VTEC (Vertical Total Electron Content) as part of the so-called Service Level 2 in Europe. Other PPP providers have not yet shared any plans to provide ionospheric corrections. QZSS CLAS is the only CLAS system providing tropospheric corrections over the Japan area. KPS will provide the atmospheric correction for PPP-RTK.

Additional data also provided by some operators includes a confidence level on the corrections, such as URA (User Range Accuracy) or equivalent, integrity, and authentication. URA is provided by QZSS and BDS, and confidence values for corrections will be also provided by Galileo (HAS Phase 2). Authentication is not yet provided but foreseen by QZSS, Galileo and GLONASS.

For the supported GNSS for correction, most servers provide GPS and their own navigation system, QZSS for QZSS CLAS and QZSS MADOCA-PPP, Galileo for Galileo HAS, BDS for BDS PPP, GLONASS for GLONASS PPP, and KPS for KPS POINT. QZSS CLAS also supports Galileo, QZSS MADOCA-PPP also supports Galileo and GLONASS, and PVS (PPP via SouthPAN) supports GPS and Galileo. For supported navigation message, LNAV is supported for all GPS and QZSS correction providers, I/NAV is only supported for Galileo except for PVS. CNAV1 is supported for BDS by BDS PPP. The PPP messages are transmitted at a rate between 2,800 bps (GLONASS PPP) and 448 bps (Galileo HAS) per satellite. Both have been proven in practice to be capable of providing high-accuracy corrections with a sufficient update rate for their intended service.

Correction parameters messages for Satellite-Based PPP are broadcast through GNSS satellites. The messages mainly include satellite orbit correction, clock correction, biases(code and phase), and user range accuracy. shown in Table 4 below.

Table 4 Correction parameters for Satellite-Based PPP

Correction parameters	BDS PPP	Galileo HAS	QZSS MADOCA-PPP		PPP via SouthPAN	KPS POINT	GLONASS
Time	**BDT**	**GST**	**QZSST**	**CLAS**	**SNT**	**KPST**	**UTC+3h**
Reference frame	BDCS	GTRF	ITRF	ECEF	ITRF2014	KTRF	ITRF2014
Satellite mask	Y	Y	Y	Y	Y	Y	Y
Satellite orbit correction	Y	Y	Y	Y	Y	Y	Y
Clock correction	Y	Y	Y	Y	Y	Y	Y
Code Biases	Y	Y	Y	Y	N	Y	Y(future)
Phase Biases	-	Y	Y	Y	N	Y	Y(future)
User Range Accuracy	Y	Y	Y	Y	Y	Y	Y
Atmospheric corrections	n/a	Available at SL2	n/a	Y	N	Y	Y(future)
Delivery Channels	SiS	SiS and HAS IDD (Internet)	SiS		SiS	SiS	SiS
Broadcasting Frequencies	B2b	E6	L6	L6D	L5	L6	L3SVO

5.3. AUGMENTED NAVIGATION MESSAGE

PPP/PPP-RTK Messages are synchronized with their own system time reference through a preamble or synchronization pattern transmitted regularly, as is the case for most GNSS signals. The satellite corrections are linked to the corrected broadcast messages through the broadcast IODs and satellite ID. Error detection and/or correction codes are added in all messages, including a checksum by CRC, encoding by LDPC, Reed-Solomon or convolutional codes.

Erreur ! Source du renvoi introuvable.2 shows the frequency of PPP/PPP-RTK signals. The signal carrier frequencies used for the PPP/PPP-RTK signals coincide with those used for GNSS: 1278.75 MHz (Galileo E6, QZSS L6, KPS L6), 1207.14 MHz (BDS B2b, SouthPAN E5b), or 1202.025 MHz (GLONASS L3). Signal power ranges across the typical GNSS power levels, from -160dBW to -153dBW. All signals are RHCP.

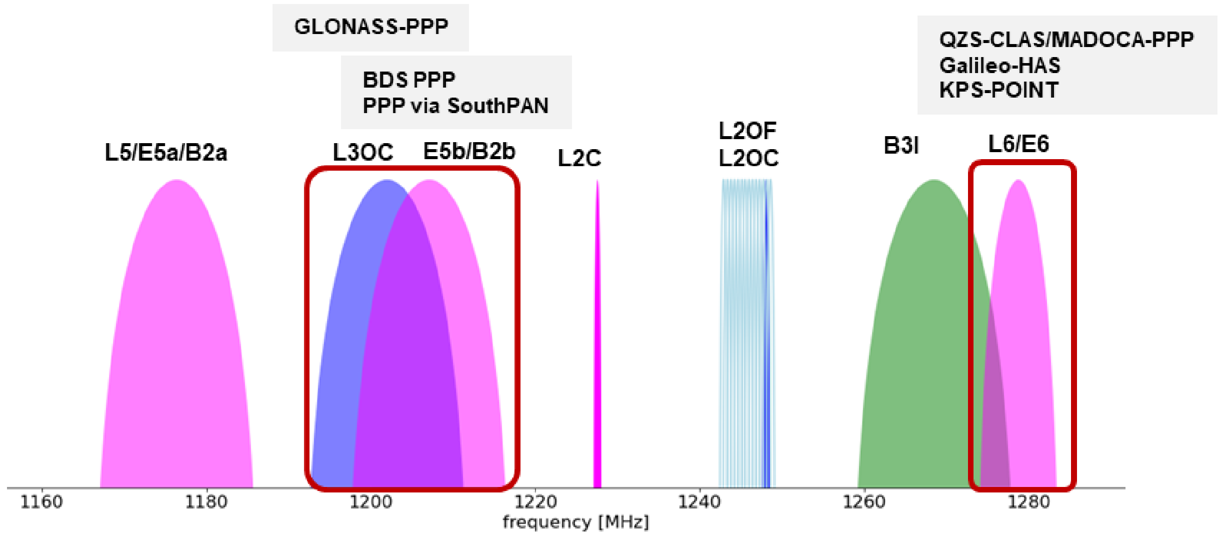

Figure 2 Power spectrums vs frequency of the main PPP/PPP-RTK signals

Concerning signal modulation, all signals are DS-SS (Direct Sequence-Spread Spectrum) using BPSK code modulations: BPSK(5) for L6/E6 (QZSS, Galileo) and L3 (GLONASS); and BPSK(10) for E5b-B2b (BDS, SouthPAN). They use shift registers (Gold, Kasami) or memory codes, at least in those publicly defined. The correction message is multiplexed with the code in a binary phase-modulated way for all cases but QZSS, which uses Code Shift Keying (CSK) to transform 250 bps into the 2000 bps mentioned above.

5.4. SERVICE COVERAGE

Satellite-based PPP services are designed to provide global or wide-area coverage. They are particularly suited to maritime operations in open ocean environments, remote maritime regions or areas without terrestrial augmentation infrastructure.

Regarding coverage, most services are provided regionally: QZSS CLAS for Japan, MADOCA-PPP for the Asia-Oceania region, PPP via SouthPAN in the Exclusive Economic Zone of Australia/New Zealand, BDS in China and its surroundings and KPS POINT in the Republic of Korea. Only Galileo HAS is provided globally, although with a temporary limitation excluding the Asia-Pacific region from the official service area during the initial service phase (Phase 1). There are plans for a global service from GLONASS PPP as well. The service coverage[19] is shown in Figure 3.

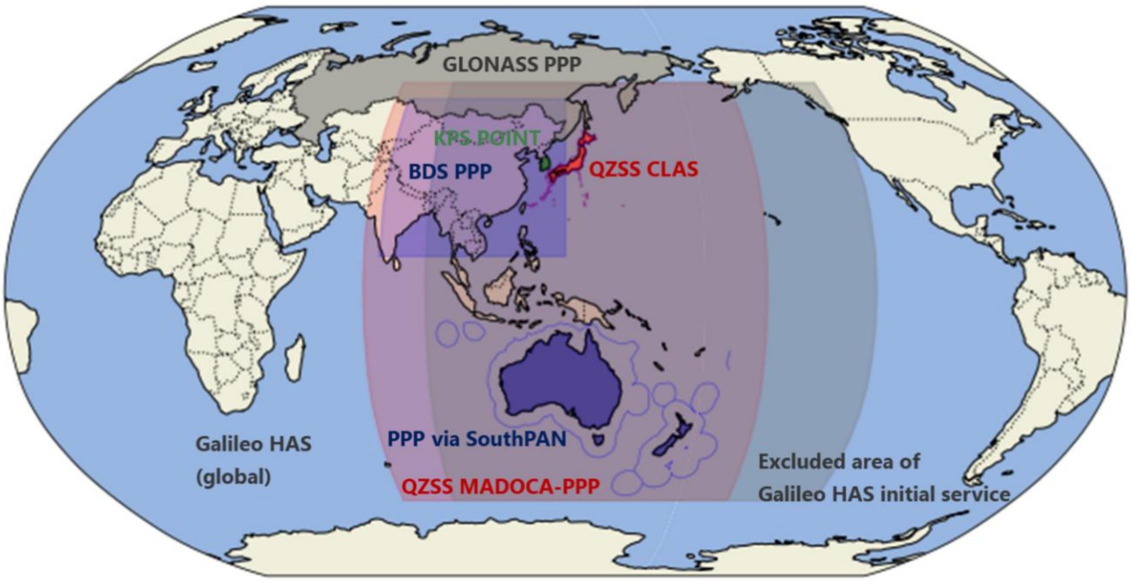

Figure 3 Service Area of GNSS satellite-based PPP

5.5. RELATIONSHIP WITH OTHER GNSS SERVICES

Satellite-based PPP services form part of a broader maritime PNT framework [20]. They provide an enhanced positioning capability and are complementary to other GNSS augmentation systems [21], including:

- Satellite-Based Augmentation Systems (SBAS), which provide integrity and regional performance improvements [22],[23];
- Differential GNSS (DGNSS), which provides localised accuracy enhancements [24];
- Ground-based precise positioning services, which provide high-accuracy positioning in coastal and port environments [2]

These systems may be used independently or in combination to support different maritime operational requirements [25], [26].

6. GNSS SATELLITE-BASED PPP SERVICE PERFORMANCE PARAMETERS

The performance of satellite-based PPP services depends on multiple factors, including GNSS constellation availability, signal quality and interference environment, receiver capability and environmental conditions. Under nominal operating conditions, satellite-based PPP services can provide decimetre-level positioning accuracy, stable positioning performance over wide areas. The convergence time required to achieve full performance may vary depending on system design and operating conditions and typically ranges from several minutes. The use of multi-GNSS constellations may improve availability and accuracy performance.

This section proposes a list of service parameters to characterize GNSS satellite-based PPP service for maritime users. The paragraphs below detail how these parameters can be understood and measured.

6.1. POSITIONING ACCURACY AND CONVERGENCE TIME

Positioning accuracy is indicated as the horizontal and vertical accuracy, both at the 95% confidence level. It relates to convergence time which is defined as the required time for a PPP solution to reach its specified performance level after initialisation. The accuracy and convergence time of each PPP system are summarized in Table 5.

Table 5 Expected positioning accuracy and convergence time for Satellite-Based PPP

	BDS PPP	Galileo HAS	QZSS MADOCA-PPP	CLAS	PPP via SouthPAN	KPS POINT	GLONASS PPP
Real-time Horizontal Accuracy(95%)	30 cm (using BDS only) 20 cm (BDS+GPS)	20 cm	30 cm	12 cm (kinematic) 6 cm horizontal, (static)	37.5 cm	10 cm	20 cm horizontal
Real-time Vertical Accuracy(95%)	60 cm (using BDS only) 40cm (BDS+GPS)	40 cm	50 cm (static)	12 cm (static) 24 cm (kinematic)	52.5 cm	20 cm	30 cm
Convergence time	30 min (using BDS only) 20 min (BDS+GPS)	300s (SL1) 100s (SL2)	30 min	60 sec (Including time to receive correction data)	OS-PVS-IOC =< 80 minutes (average 45-55 minutes) OS-PVS-FOC =< 40 minutes	TBD	1200s

6.2. SIGNAL AVAILABILITY

The signal is considered available when provided according to its specification. For maritime, signal availability is the percentage of time when the SiS is provided by the GNSS throughout the specified service coverage area.

6.3. SERVICE AVAILABILITY

The probability that the system provides the necessary information enabling users to determine their position with the specified accuracy within the service coverage area.

6.4. SERVICE CONTINUITY[1]

The probability that, assuming a fault-free receiver, a user will be able to determine position without any interruption under specified accuracy applicable for a particular operation within the service coverage area.

6.5. INTEGRITY

Integrity performance should be assessed in accordance with maritime requirements and expressed in terms of alert limit, time to alarm, integrity risk. The level of integrity provided by satellite-based PPP services depends on system design, monitoring capability, and service implementation.

6.6. SERVICE COVERAGE AREA

The maritime service coverage area is a designated geographical area where, taking into account the radio frequency environment, PPP/PPP-RTK is adequate to provide the service performance required by specific maritime operations.

1 This definition is not entirely consistent with the definition required by IMO Resolution A.915(22).

7. GNSS SATELLITE-BASED PPP MARITIME SERVICE PROVISION SCHEME

A scheme for providing the users with the appropriate GNSS satellite-based PPP maritime services, including the provision of maritime safety-related information to the end users.

This section describes an example of this scheme, with relevant stakeholders involved, including the interfaces between them as well as the provision of GNSS satellite-based PPP service-related Maritime Safety Information (MSI) to the end users. The picture below presents this high-level service provision model schematically:

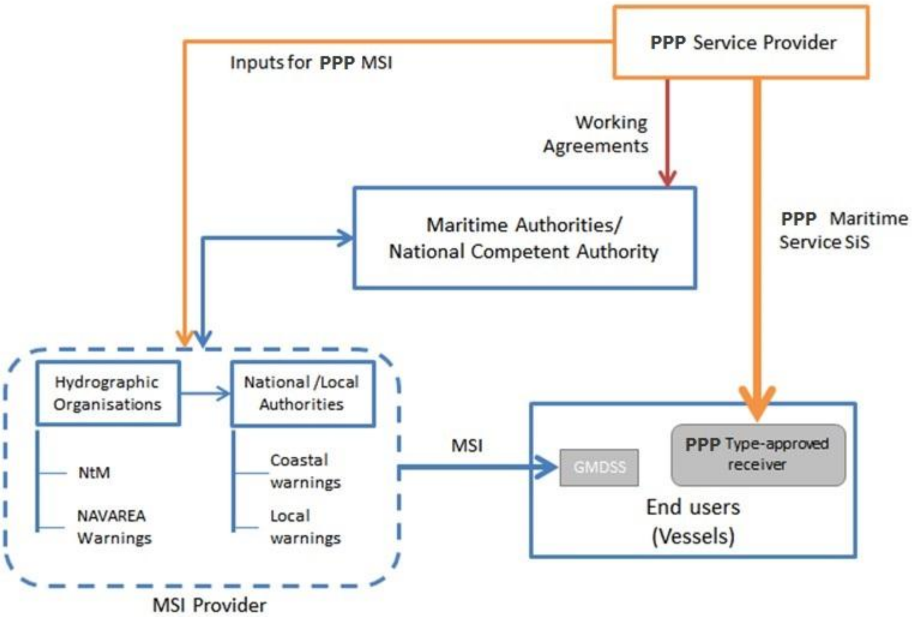

Figure 4 GNSS Satellite-based PPP Maritime Service Provision Scheme

This example considers the reception of the PPP SiS directly on board the vessels equipped with type-approved receivers. The stakeholders involved in this high-level service provision model, including their expected roles and responsibilities, are described below:

7.1. THE PPP SERVICE PROVIDER

The PPP Service Provider will be the entity which provides the PPP Maritime Service. The PPP Service Provider will also be responsible for establishing and supporting all the required operational interfaces with the other stakeholders (end users, Marine Aids to Navigation c authorities, and MSI Providers), including the generation of any PPP MSI proposals to be distributed by the MSI providers to the end users of the service.

7.1.1. PPP SERVICE PROVIDER RESPONSIBILITIES

The PPP Service Provider responsibilities can be structured in four main blocks, as follows:

- Operation and Maintenance: the PPP Service Provider should continuously monitor the service to detect and manage service disruptions and performance degradations, and inform the users. The information regarding planned and unintended PPP service degradations and unavailability is delivered to the MSI provider.
- Performance Verification: the PPP service provider should verify that the service is performing according to its specifications.
- Publication of information: the PPP service provider should make the service description publicly available and also report scheduled maintenance activities and planned unavailability. The PPP service provider could also provide service performance reporting and support to all the users.

- Working agreements: working agreements can be adopted to formalize the PPP Service Provider's service commitment and its engagement with administrations, including:
  - Roles, responsibilities, and liability scheme.
  - Assurance of the long-term operation of the PPP service and backward compatibility.
  - Service offered and its characteristics.
  - Service performance in compliance with IMO Requirements and maritime service coverage area.
  - PPP MSI provision (generation and distribution procedure).
  - Costs of the service, e.g., free of charge.
  - Legal data recording needs.

7.1.2. MARINE AIDS TO NAVIGATION AUTHORITIES

Marine Aids to Navigation authorities are encouraged to work mutually with the PPP maritime service provider and consider, beyond their existing roles, undertaking additional responsibilities for authorities to deliver the service or the maritime safety information. Authorities are encouraged to monitor the service and ensure that the appropriate MSI is being conveyed to the user. For MSI, existing internationally agreed procedures should be followed.

7.2. END USERS

The end users are the mariners/vessels using the PPP Maritime Service SiS. End users that wish to use this service need to use a type-approved receiver[18] once the appropriate standards are in place. The end users are also the recipients of the MSI related to PPP.

7.3. MSI PROVIDER

The MSI provider is encouraged to promulgate to the users ,the MSI related to PPP Maritime Service status and degradation, using approved procedures.

The PPP Service Provider should send details of vessel service performance indicators, e.g. service performance degradation to the MSI provider, in a format agreed between these parties. The MSI provider[27] will continue to use the established procedures and channels for the vessel service performance indicators. Depending on the specific characteristics of the PPP service performance indicators, the MSI provider will distribute the information as Navigational Warnings (NAVAREA, coastal or local warnings)[2,3] or Notices to Mariners (NtM)[4].

8. OPERATIONAL CONSIDERATIONS

Satellite-based PPP services are suitable for maritime applications requiring global or wide-area positioning, operation in areas without local infrastructure. Typical use cases include ocean navigation, offshore operations, Long-distance voyage support. Satellite-based PPP services may have limitations, such as convergence time before full performance is achieved, sensitivity to signal blockage and interference, dependence on satellite availability. Satellite-based PPP services may be integrated with Inertial Navigation Systems (INS), other GNSS augmentation systems, multi-sensor navigation systems[19]. Such integration may improve robustness, continuity, and resilience.

8.1. MASS

Maritime Autonomous Surface Ships (MASS) is defined by IMO as being: A ship which, to a varying degree, can operate independently of human interaction. The MASS should be able to navigate to minimise the risks of grounding, collision, and environmental impact and to communicate its limitations and navigational intentions to

[2] NAVAREA warning is the MSI of temporary nature applicable to one of the 21 navigational areas in the world.
[3] Coastal or local warnings are the MSI of temporary nature applicable to a coastal or local area.
[4] Notices to Mariners (NtM) is the MSI permanent information published by the National Hydrographic Office.

other vessels. Navigational systems should identify all navigation hazards, fixed or mobile, and measure and interpret environmental data. The navigational systems should be designed and constructed to:

- Enable their operation in all reasonably foreseeable operating conditions.
- Operate in a predictable manner with a level of integrity commensurate with operational and safety requirements.
- Meet requirements for watertight, weathertight, and fire integrity.
- Minimise the risk of initiating fire and explosion.
- Enable the maintenance and repair in accordance with the maintenance philosophy.
- Allow for automated docking.

Satellite-based PPP provides high accuracy of operation to MASS during navigation in harbour entrances and harbour approaches without the assistance of the ground broadcasting system. Once the PPP service converges, it can provide stable and continuous high-precision location service at the centimetre level. This will be critical in enabling MASS to navigate safely and manoeuvre as required by international regulations.

8.2. OFFSHORE OPERATIONS

PPP can support offshore drilling and construction by providing an accurate and reliable method to maintain precise locations, which is essential for the safety and efficiency of these operations.

- Critical for complex offshore activities. Offshore operations such as pipe-laying, drilling, and maintenance require high levels of accuracy to ensure proper alignment and avoid costly errors. PPP provides centimetre-level precision, which is essential when demanding exact positioning.
- Support for Dynamic Positioning (DP) systems. Many offshore vessels and platforms use dynamic positioning systems to maintain their location without the need for anchors. PPP enhances these systems by supplying highly accurate geospatial data, enabling vessels to remain stationary even when affected by currents, waves, or wind. This stability is especially important during complex and high-stakes activities such as drilling or construction in challenging sea conditions.
- Minimize the risk of drifting. For vessels such as survey ships, floating production systems, or support vessels, precise station-keeping is necessary to avoid drifting, which could lead to accidents or operational disruptions. PPP ensures that vessels remain within defined positional limits, reducing the risk of collisions, environmental damage, or costly downtime due to repositioning.
- Increased operational efficiency and safety. By providing precise and continuous positioning data, PPP helps reduce the margin for error in offshore operations. This improved accuracy enhances both operational efficiency and safety, preventing incidents that could compromise the integrity of critical infrastructure or endanger personnel. In unpredictable and often harsh ocean environments, this level of precision is indispensable.

8.3. PORT AND HARBOUR OPERATIONS

Port and harbour operations require accuracy of position to enhance safety and efficiency in critical activities, such as:

- Safe and efficient docking for large vessels: Large ships, such as container vessels and cruise liners, require precise navigation when entering or leaving ports, especially in crowded harbours or during challenging weather conditions. PPP provides highly accurate positioning, enabling these vessels to dock safely and efficiently, minimizing the risk of collisions or grounding, even in narrow or congested areas.

- Accurate dredging operations: Maintaining safe depths in ports and harbours is essential for accommodating large vessels. PPP ensures precise positioning during dredging operations, which is critical for removing sediment and maintaining the necessary depths for vessel passage. Accurate dredging also optimizes costs by ensuring only the necessary areas are dredged to the required depth.
- Precision in harbour infrastructure construction: Building breakwaters, piers, and other harbour structures requires a high degree of accuracy to ensure structural stability and positional accuracy. PPP supports precise construction by providing accurate location data for construction teams, ensuring that these structures are built to the correct specifications and in the right positions.
- Enhanced automation in port machinery: Modern ports increasingly rely on automated systems such as cranes and transport vehicles to handle containers and other cargo. PPP enhances the precision of these automated systems by ensuring accurate positioning of cranes and machinery, enabling efficient loading and unloading of goods. This not only streamlines port operations but also reduces human error and improves overall safety.
- Weather-independent operations: PPP remains reliable even in challenging weather conditions, providing continuous and accurate data. This allows for uninterrupted port operations regardless of reduced visibility or adverse environmental factors, further ensuring the safety and efficiency of vessel movements and cargo handling.

8.4. SURVEY OPERATIONS

Accurate seabed mapping for navigation: Hydrographic surveys rely on high-precision positioning to map the seabed, coastal areas, and underwater hazards. PPP ensures that these surveys provide the necessary details to support safe navigation, identifying potential obstacles or changes in the seabed that could pose risks to vessels. This level of accuracy is crucial for charting safe shipping routes and preventing accidents.

Supporting port development: Accurate hydrographic data is vital for the planning and development of ports and harbours. PPP ensures the precise mapping of underwater features and topography, aiding in the design of new infrastructure such as piers, docks, and dredging zones. With PPP, engineers can make informed decisions based on reliable data, ensuring that development projects proceed smoothly and safely.

Critical for environmental assessments: Environmental assessments often require precise mapping of coastal and underwater areas to monitor ecosystems, assess the impact of construction, and detect changes in marine environments. PPP enhances the accuracy of hydrographic surveys used for these assessments, providing data that is vital for protecting marine life and coastal habitats, ensuring that development or industrial activities are environmentally sustainable.

Support underwater installations: Pipelines, cables, and other underwater installations rely on precise mapping and monitoring to ensure their integrity. PPP can realize highly accurate surveys and monitoring systems, enabling precise placement of these critical infrastructures. Additionally, PPP supports maintenance operations by providing exact positional data for inspecting and repairing underwater assets, minimizing the risk of damage and reducing downtime.

Improve safety and efficiency in surveying: Hydrographic surveys conducted with PPP improve both safety and efficiency. By providing real-time, highly accurate positioning data, surveyors can avoid costly errors, complete surveys more quickly, and reduce the likelihood of revisiting sites due to inaccurate data. This is particularly important in complex environments where precision is vital to avoid hazards or disruption to marine operations.

8.5. SEARCH AND RESCUE

In search and rescue operations, PPP provides rescue vessels and aircraft with highly accurate location data in the second-generation beacons[28], enabling quicker response times and more effective rescue efforts, particularly in bad weather or poor visibility. The system enables real-time tracking of vessels in distress, providing rescuers with accurate and up-to-date information for planning and coordination.

Dredging is the removal of sediments and debris from the bottom of lakes, rivers, harbours, and other water bodies. It is a routine necessity in waterways around the world because sedimentation—the natural process of sand and silt washing downstream—gradually fills channels and harbours. Dredging often is focused on maintaining or increasing the depth of navigation channels, anchorages, or berthing areas to ensure the safe passage of ships. Vessels require a certain amount of water to float and not touch bottom, so a Dredge Positioning system is often used in combination with GNSS Real-time Kinematic (RTK) positioning devices to show a superimposed view of the dredge location in real-time over the survey. GNSS satellite-based PPP service can provide real-time and high-accuracy location without extra augmentation devices. It precisely identifies the location of the attachment at the end of the excavator boom/stick assembly. Together with the dredge positioning system, displayed is a survey or map of an as-built-coloured bathometric surface of the area to be dredged. It decreases the potential for damage by increasing situational awareness, keeping the operator alerted when the digging attachment is positioned too close to environmental borders, infrastructure, or any other areas where the digging attachment can cause undesired damage.

9. ABBREVIATIONS

BEIDOU/BDS	Chinese Global Navigation Satellite System
BDCS	BDS Coordinate System
CHAYKA	Russian long range navigation system
CLAS	Centimetre Level Augmentation Service
DGNSS	Differential GNSS
EGNOS	European Geostationary Navigation Overlay Service
Galileo	European GNSS
Galileo HAS	Galileo High Accuracy Service
GLONASS	Russian Global Navigation Satellite System
GMDSS	Global Maritime Distress and Safety System
GNSS	Global Navigation Satellite System such as Galileo, GPS, GLONASS or BEIDOU.
GPS	U.S. Global Positioning System
GTRF	Galileo Terrestrial Reference Frame
IALA	International Organization for Marine Aids to Navigation
IEC	International Electrotechnical Commission
IGS	International GNSS Service
IMO	International Maritime Organization
IRNSS	Indian Regional Navigation Satellite System
ITRF	International Terrestrial Reference Frame
KPS	Korean Positioning System
KTRF	Korean Terrestrial Reference Frame
MADOCA-PPP	Multi-GNSS Advanced Orbit and Clock Augmentation - Precise Point Positioning
PNT	Position, Navigation, and Time
POINT	Precise POsitioning and INTegrity monitoring
PPP	Precise Point Positioning
QZSS	Quasi-Zenith Satellite System
RTK	Real Time Kinematic
SBAS	Satellite-based Augmentation System
SDCM	System of Differential Correction and Monitoring
WWRNS	World Wide Radio Navigation Systems

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ANNEX A EXISTING AND PLANNED GNSS SATELLITE-BASED PPP SYSTEMS

ANNEX A.1. BDS PPP B2B

The BDS PPP-B2b signal is designed to provide PPP service for GNSS and their combinations. For each satellite navigation system, the reference broadcast navigation messages corresponding to various corrections are:

- BDS: PPP-B2b information is used to correct the CNAV1 navigation messagesofB1C signal.
- GPS: PPP-B2b information is used to correct the LNAV navigation messages.
- Galileo: PPP-B2b information is used to correct the I/NAV navigation messages.
- GLONASS: PPP-B2b information is used to correct the L1OCd navigation messages.

Signal Mask is a 16-bit field that indicates the signals of the GNSS identified by GNSS ID, and provides consistent biases in the Code Bias and Phase Bias content blocks. The list of signals is provided in Table 1. For each signal, “1” indicates that biases are provided and “0” indicates that they are not. The MSB of the field corresponds to Signal Index = 0.

Table 1 Signal Index Table

Signal Index	Galileo	GPS
0	E1-B I/NAV OS	L1 C/A
1	E1-C	Reserved
2	E1-B + E1-C	Reserved
3	E5a-I F/NAV OS	L1C(D)
4	E5a-Q	L1C(P)
5	E5a-I + E5a-Q	L1C(D+P)
6	E5b-I I/NAV OS	L2 CM
7	E5b-Q	L2 CL
8	E5b-I + E5b-Q	L2 CM + CL
9	E5-I	L2 P
10	E5-Q	Reserved
11	E5-I + E5-Q	L5 I
12	E6-B C/NAV HAS	L5 Q
13	E6-C	L5 I + L5 Q
14	E6-B + E6-C	Reserved
15	Reserved	Reserved

ANNEX A.2. GALILEO HAS

On January 24th, 2023, the Galileo HAS Initial Service was declared operational, and Galileo became the first Global Navigation Satellite System (GNSS) to provide free-of-charge, high-accuracy Precise Point Positioning (PPP) corrections worldwide, both through the Galileo signal in space (E6-B) and over the internet through Galileo HAS IDD.

The service allows the user to achieve improved positioning compared to the performance of the Galileo OS (Open Service). The typical positioning performance is based on the Galileo HAS corrections performance and the implementation of the performance characterization user algorithm (HAS-UA).

The HAS-UA is a real-time Precise Point Positioning (PPP) algorithm that processes the corrections provided by HAS and calculates position, velocity and time at the receiver. The Galileo HAS-UA can work in either double frequency or triple frequency modes, supporting both Galileo single constellation and Galileo + GPS dual constellation mode.

Specifically, the HAS-UA supports the following working modes (in case of Galileo-only): dual frequency modes E1/E5a, E1/E5b, E1/E6-B; and triple frequency mode E1/E5a/E6-B.

The HAS Initial Service, enabled by the current Galileo infrastructure, allows the provision of the so-called HAS Service Level 1 (not all SL1 products are available at Initial Service; certain areas are not covered). Even if the HAS Initial Service performances do not reach the HAS Full Service targets yet, the Galileo HAS Initial Service provides a decimeter-level performance as standard. The full description of the HAS Initial Service, including performance levels and coverage, is provided in the HAS Service Definition Document (SDD).

In the near future, the Galileo HAS Full Service will provide two Service Levels (SL). It will expand the Initial Service version of the so-called SL1 to support more demanding performance targets and achieve a global service area. Additionally, the Galileo HAS Full Service will provide a regional, Europe-wide Service Level (SL2). Their main features are included hereafter:

SL1:

- Service area: global coverage, hence addressing the areas currently excluded from the HAS service area
- Products: orbits and clocks corrections, code and phase biases
- Delivery channels: HAS Signal-In-Space (SIS) and HAS Internet Data Distribution (IDD)
- User performance accuracy (95%): 20 cm (horizontal) and 40 cm (vertical)
- Availability target: 99%
- User performance convergence time: 300 seconds

SL2:

- Service area: European coverage
- Products: SL1 products and atmospheric corrections
- Delivery channels: HAS SIS and HAS IDD
- User performance accuracy targets (95%): 20 cm (horizontal) and 40 cm (vertical)
- Availability target: 99%
- User performance convergence time: 100 seconds

ANNEX A.3. CLAS

The Centimeter-Level Augmentation Service (CLAS) is a regional high-precision Global Navigation Satellite System (GNSS) augmentation service provided by the Japanese Quasi-Zenith Satellite System (QZSS). The service broadcasts precise correction messages via the QZSS L6D signal, including satellite orbit and clock corrections, atmospheric corrections, and other auxiliary parameters required for high-accuracy positioning. By applying these broadcast corrections, users within Japan can realize real-time positioning with centimeter-level accuracy.

From the perspective of system architecture, CLAS is an open, satellite-based augmentation service that follows a Precise Point Positioning–Real-Time Kinematic (PPP-RTK) paradigm. The correction information is generated by a ground-based monitoring and processing network and disseminated to users through QZSS satellites, enabling wide-area, real-time, high-precision positioning. As a typical implementation of high-precision GNSS augmentation in Japan, CLAS provides an important reference framework for the design and evaluation of satellite-broadcast PPP-RTK services, and constitutes multi-GNSS positioning architectures alongside other contemporary high-accuracy augmentation systems, such as the Galileo High Accuracy Service (HAS) and the BeiDou PPP-B2b service.

ANNEX A.4. QZSS MADOCA-PPP

QZSS MADOCA-PPP leverages the Quasi-Zenith Satellite System (QZSS) to provide advanced orbit and clock augmentation for Precise Point Positioning (PPP). This system aims to enhance the accuracy and reliability of PPP services, particularly in regions where traditional GNSS signals may be weak or unavailable. By utilizing the unique geometry of the QZSS satellites, MADOCA-PPP is able to offer corrections that significantly improve positioning performance.

One of the key advantages of QZSS MADOCA-PPP is its ability to provide regional enhancements. Unlike some global PPP services, QZSS MADOCA-PPP focuses on improving positioning accuracy within specific geographic areas, such as Japan and surrounding regions. This regional focus tailors corrections and improves performance in these critical areas.

In addition to regional enhancements, QZSS MADOCA-PPP also supports multi-GNSS capabilities. This means that it can utilize signals from multiple global navigation satellite systems, including GPS, QZSS, Galileo, GLONASS, and BeiDou,, to provide even more accurate and reliable positioning. By combining signals from multiple systems, MADOCA-PPP is able to mitigate the impact of signal outages and multi-path errors, further enhancing its performance.

Overall, Its focus on regional enhancements and multi-GNSS capabilities is designed for applications that require high-accuracy positioning, such as marine navigation, and surveying. As the technology continues to evolve, QZSS MADOCA-PPP is poised to play an increasingly important role in the future of precise point positioning.

Compact SSR Signal mask: The sequence of bits which defines the selected signals for correction messages defined for each GNSS, as listed in Table 2.

Table 2 Compact SSR signal mask

Compact SSR Signal mask	GPS	GLONASS	Galileo	BeiDou	QZSS	SBAS
0	L1 C/A	G1 C/A	E1 B I/NAV OS/CS/Sol	B1I	L1 C/A	L1 C/A
1	L1 P	G1 P	E1 C no data	B1 Q	L1 L1C(D)	L5I
2	L1 Z-tracking	G2 C/A	E1 B+C	B1I+Q	L1 L1C(P)	L5 Q
3	L1 L1C(D)	G2 P	E5a I F/NAV OS	B3 I	L1 L1C(D+P)	L5I+Q
4	L1 L1C(P)	G1a(D)	E5a I/Q no data	B3 Q	L2 L2C(M)	
5	L1 L1C(D+P)	G1a(P)	E5a I+Q	B3I+Q	L2 L2C(L)	
6	L2 L2C(M)	G1a(D+P)	E5b I/NAV OS/CS/Sol	B2I	L2 L2C(M+L)	
7	L2 L2C(L)	G2a(D)	E5b I/Q no data	B2 Q		7
8	L2 L2C(M+L)	G2a(P)	E5b I+Q	B2I+Q	L5 Q	8
9	L2 P	G2a(D+P)	E5I	L5I	L5I+Q	9
10	L2 Z-tracking	G3 I	E5 Q		L6D	10
11	L5 I	G3 Q	E5I+Q		L6P	11
12	L5 Q	G3 I+Q	E6 B		L6E	12
13	L5I+Q		E6 C		L1 C/B	13

Table 3 Augmented Navigation Message

GNSS	Applicable navigation message extension in L6 message type ID	
	0	1
GPS	LNAV	CNAV/CNAV2
GLONASS (FDMA)	GLONASS-M	GLONASS-M
GLONASS (CDMA)	GLONASS-KGLONASS-K	GLONASS-KGLONASS-K
Galileo	I/NAVI/NAV	I/NAVI/NAV
QZSS	LNAV	CNAV/CNAV2
BeiDou	D1	D1

ANNEX A.5. PPP VIA SOUTHPAN (PVS)

South-PAN, which stands for Southern Positioning Augmentation Network, offers an augmented navigation message that enhances the precision and reliability of PPP services in southern regions. By leveraging a network of ground stations and advanced algorithms, South-PAN provides corrections to the standard GNSS signals, significantly improving positioning accuracy.

One of the notable features of PPP via South-PAN (PVS) is its ability to provide real-time corrections. These corrections are transmitted to users via satellite, ensuring that they receive the most up-to-date and accurate positioning information. This real-time capability is crucial for applications that require high precision and reliability, such as aviation, marine navigation, and surveying.

Moreover, South-PAN is designed to be interoperable with other global navigation satellite systems, including GPS, Galileo, and QZSS. This interoperability benefits users from the combined strengths of multiple systems, further enhancing the accuracy and reliability of PPP services. By utilizing signals from multiple systems, South-PAN can mitigate the impact of signal outages and multipath errors, providing a more robust and reliable positioning solution.

In addition to real-time corrections and interoperability, PPP via South-PAN (PVS) also offers high availability and performance convergence time. With an availability target of 99% and a user performance convergence time of 100 seconds, South-PAN ensures that users can rely on accurate and reliable positioning information even in challenging environments.

Overall, its real-time corrections, interoperability with multiple systems, and high availability is designed for applications that require high-accuracy positioning. As the technology continues to evolve, PPP via South-PAN (PVS) is poised to play an increasingly important role in the future of precise point positioning in southern regions.

ANNEX A.6. KPS POINT

The Korean Positioning System (KPS) is the national satellite navigation system under development by the Republic of Korea, with the full constellation of eight satellites scheduled for completion by 2035. Once operational, KPS will deliver five categories of services: Open Service, Meter-level Service, Centimeter-level Service, Search and Rescue (SAR) Service, and Satellite-Based Augmentation Service (SBAS).

Among these, the centimeter-level service, branded as KPS POINT, represents one of the most advanced features of the system. This service is designed to support emerging applications that demand extremely precise positioning, including autonomous navigation, smart port logistics, unmanned aerial systems, precision agriculture, and other industrial fields where sub-decimeter accuracy is essential.

KPS POINT will be enabled through PPP-RTK (Precise Point Positioning-Real Time Kinematic). In this approach, KPS satellites will provide atmospheric corrections to significantly reduce errors, allowing user receivers to achieve centimeter-level accuracy via L6 (1278.75 MHz). This capability addresses the limitations of conventional GNSS signals, which are affected by ionospheric and tropospheric disturbances, and ensures improved accuracy and reliability.

The Ministry of Oceans and Fisheries of the Republic of Korea has already launched a ground-based precise positioning service in December 2024, making centimeter-level accuracy available nationwide. By distributing correction information through terrestrial communication and broadcasting networks, this service reduces the typical 10-meter error of GNSS down to approximately 5 cm. Building on this achievement, KPS plans to expand beyond terrestrial infrastructure by transmitting correction data directly via satellites, reducing dependency on ground networks and enabling high-precision positioning through KPS itself.

Once the constellation of eight satellites is fully deployed by 2035, KPS POINT will be officially launched as a satellite-based service. It will not only advance technological performance but also serve a wide range of sectors, including maritime, land-based, and aviation applications. From autonomous ships and drones to air traffic management and smart city mobility, KPS POINT will provide highly reliable and precise positioning services that enhance efficiency and safety across multiple domains.

ANNEX A.7. GLONASS PPP

GLONASS, the Russian global navigation satellite system, has also made significant strides in precise point positioning technology. GLONASS PPP leverages the constellation of GLONASS satellites and a network of ground stations to provide highly accurate positioning services. Similar to South-PAN and KPS POINT, GLONASS PPP offers real-time corrections that are transmitted to users via satellite, ensuring they receive the most up-to-date and precise positioning information.

These real-time corrections are crucial for applications that require high precision and reliability, such as aviation, marine navigation, and surveying. By incorporating real-time data, GLONASS PPP can adapt to changing conditions and provide continuous, accurate positioning, even in challenging environments.

In addition to real-time corrections, GLONASS PPP supports multi-GNSS capabilities. This means it can utilize signals from multiple global navigation satellite systems, including GPS, Galileo, and QZSS, to further enhance positioning accuracy and reliability. By combining signals from these different systems, GLONASS PPP can mitigate the impact of signal outages and multipath errors, providing a more robust and reliable positioning solution.

Furthermore, GLONASS PPP is designed to be interoperable with other PPP services and systems. This interoperability allows users to seamlessly integrate GLONASS PPP with their existing positioning infrastructure, expanding its potential applications and use cases. Whether users are in Russia or other regions, GLONASS PPP offers a high-accuracy, reliable, and versatile positioning solution that meets the demands of modern positioning technology. As technology continues to evolve, GLONASS PPP will be poised to play an increasingly important role in the future of precise point positioning globally.