ESA/PB-NAV(2018)35
Paris, 26 October 2018
(Original: English)

EUROPEAN SPACE AGENCY

NAVIGATION PROGRAMME BOARD

NAVISP Element 1 Work Plan for 2019

Subject

This document presents the NAVISP Element 1 Work Plan 2019 activities.

Required action

The participating States in NAVISP Element 1 are invited to approve, by simple majority, the Element 1 Work Plan for 2019.

Voting rights and required majority

Simple majority of the Participating States in the Element 1 of the NAVISP Programme (AT, BE, CZ, D, DK, FI, FR, NL, NO, RO, CH, UK) representing at least half of the contributions to this Element.

Legal Basis

Act in Council on the Introduction of Weighted Vote in the Agency's Optional Programmes (ESA/C/CCXXIX/Act 1 (Final) attached to ESA/C(2012)102).
Article 3 (d) of the Implementing Rules of the NAVISP Programme.

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1. INTRODUCTION

Activities under Element 1 of the Navigation Innovation and Support Programme (NAVISP) are defined and implemented according to an annual work plan to be prepared and proposed by the Agency, and to be approved by participating States in Element 1. The annual work plan is prepared on the basis of appropriate consultation with the participating States and ex-ante coordination with the European Commission (EC) and the European GNSS Agency (GSA).

This document presents the Element 1 Work Plan for 2019.

2. PREPARATION OF NAVISP ELEMENT 1 WORKPLAN FOR 2019

In order to collect the most promising ideas and proposals and be able to prepare the Element 1 Work Plan for 2019, the Executive has again applied the well proven ‘funnel scheme’, which was instrumental for the approval of Work Plans 2017 and 2018.

The funnel scheme is based on:

- an ESA-wide consultation, to populate the work plans according to well-established guidelines;
- external inputs, not only based on recommendations from recognised experts in the PNT sector, but also from consultative workshops organised by Participating States.

Proposals have taken into account preliminary comments received through the intermediate round of formal consultations with the EC, GSA and participating States on the ‘Draft NAVISP Element 1 Work Plan 2019’ (ESA/PB-NAV(2018)30) presented at the 107th PB-NAV meeting.

3. STATUS OF COORDINATION

The Element 1 Work Plan for 2019 has therefore been shared with the EC and GSA through two rounds of formal consultation on both its draft and final versions. This process has been carried out strictly in line with “Coordination between the EC-GSA and ESA on NAVISP Programme Activities” (ESA/PB-NAV(2016)34). Comments received by the EC and GSA have been taken into account, and text describing the proposed activities has been updated for the sake of clarity.

EC and GSA experts will support the activities implementation as requested during coordination.

4. RATIONALE AND DESCRIPTION OF PROPOSED ACTIVITIES

The NAVISP Element 1 workplans support the foundations for future innovative PNT developments, the aim being to attract industry interest in the wider PNT domain and offer the possibility of developing new solutions by accessing and combining relevant space and non-space know-how, techniques and technologies.

The activities proposed in the 2019 Work Plan have again been grouped according to the same broad themes as proposed for the previous workplan, i.e.:

- Theme 1: Emerging New Space-Based PNT Concepts;
- Theme 2: Innovative Use of Space-Based Solutions in the PNT Context;
- Theme 3: Proof of concept of promising PNT Techniques and Technologies.

It is here recalled that the above classification per theme does not exclude using more granular groupings according to subject areas, as mentioned in previous work plans and here re-listed as follows:

- Timing techniques, clock technologies, quantum technologies and clocks;
- Low-power technologies;
- Autonomy;
- Mobile devices:
- Resilience and trust;
- PNT for environmental matters:
- Role of GNSS for in-orbit servicing;
- Complementary non-GNSS positioning.

4.1. Theme 1: Emerging New Space-Based PNT Concepts

The underlying rationale of Theme 1 has already been described and shared in the approval process for the previous Element 1 Work Plans for 2017 and 2018. Ultimately, the objective of the theme is to contribute to detailed understanding of emerging trends and investigate PNT technologies complementary to or alternative to current GNSS evolution trends with the aim of stimulating European industry to reap the benefit of these potential developments.

4.1.1. NAVISP-El1-027: Alternative Space-based PNT Data Layer

In the last years, there has been fast progress in satellite on-board computing achieved by the satellite telecommunication industry. On-board processors are more performant, with less mass, volume and power consumption.

As regards current and evolving space-based PNT data layer services (e.g. private or public GNSS data augmentations), they usually retransmit data computed on-ground via satellite and their architectures do not exploit the benefits that technological innovation in on-board processing could bring against new threats and challenges. These benefits may range from reduction of latency for data collection, processing and broadcast to increased robustness against physical and cyber-attacks, as jamming and spoofing of the satellite up-link.

The main objective of the proposed activity is to study new, innovative concepts and trade-off main design drivers for a PNT data layer system based on on-board processing, alternative to conventional on-ground computation based systems.

Alternative architectural concepts could consist of up-linking Monitoring Station (MS) data directly to satellites where PNT data layer messages are processed on-board and broadcast to users. In this architectural concept, the following features are typically envisaged:

- each Monitoring Station is equipped with a satellite uplink terminal;
- there is no real-time terrestrial network to transmit data to a central processing facility on-ground;
- PNT data layer messages and signals are processed and generated on-board, with up-link data received through e.g. a spot beam antenna.

The tasks to be performed will include:

- definition of high-level architectural concepts with particular focus on the payload features and main constituents, identifying main functions and data flows for each component and performing main system trade-off’s;
- analysis of achievable end-to-end performance, studying the cases where improvements derived from alternative architectures are expected, for instance on data latency, and providing insight into the main design drivers;
- assessment of status of existing technology vis-à-vis functional and architectural needs, identifying areas for technology evolutions such as radiation-hardened space computer or on-board processing capabilities;
- identification of potential improvements in robustness versus cyber-attacks, jamming and spoofing.

The main results of the activity will provide an assessment of the interest in alternative architectures based on on-board processing, with insight in the main architectural trade-off’s and identification of areas where technology evolution is a prerequisite.

Results from previous related ESA activities will be duly considered and assessed. Close coordination with GSA will be ensured.

Funding required: €250k	*Duration:* 12 months	*ITT issue:* Q2 2019

4.2. Theme 2: Innovative Use of Space-Based Solutions in the PNT Context

Theme 2 focuses on the captive PNT market segments where there is potential for introducing or increasing the penetration of space-based PNT.

Differently from previous Work Plans, the only proposed activity for Theme 2 in Work Plan 2019 does not address regulated market domains and rather focusses on new scientific applications.

4.2.1. NAVISP-El1-028: GNSS Science with Commercial Aircraft

Usage of commercial aircraft and vessels, as platforms for crowdsourcing science and remote sensing, is under study by organisations like the International Hydrographic Organization (IHO) in its Crowdsourced Bathymetry Working Group, or by private companies for imaging and radar applications.

Some advanced passive GNSS-based processing techniques (e.g. exploiting simultaneously direct and reflected signals) applied to commercial aircraft could provide very useful scientific data with higher spatial and temporal resolution than current spaceborne instruments.

Past studies (i.e. PARIS-alpha project) and industrial initiatives (started in an ESA Business Incubator Centre) have already assessed the feasibility of using planes for remote sensing (Altimetry GNSS-R in PARIS-alpha, GNSS-RO in ARO, imaging and radar in Skyflox). In addition, experimental GNSS-R flight campaigns have been carried out in the past.

Short time and small spatial scale ocean, atmospheric and land processes could be measured with the proposed strategy: ionospheric data, sea levels, wind profiles, soil moisture, vegetation and climate change variables.

Furthermore, these measurements could potentially allow the study of Earth processes in areas (i.e. scatterometry in coastal areas or ionosphere in the ocean) and in a scale not covered by spaceborne payloads, constituting then an excellent complement.

The objectives of the proposed activity are to:
- evaluate benefits of the crowdsourcing strategy based on commercial aircraft in terms of coverage, revisiting time and enabled science applications;
- determine capabilities of the state of art of passive remote sensing techniques based on GNSS (multi-frequency multi-constellation). If feasible, the scientific opportunities emerging from this proposal are enormous with a higher spatial and temporal resolution than those provided by spaceborne data.

The tasks to be performed will include:
- assessing the end-to-end performance of the state of the art of passive remote sensing techniques based on GNSS;
- identifying potential scientific fields of application and their requirements;
- assessing feasibility and economic viability of the crowdsourcing strategy based on commercial aircraft in terms of coverage and revisiting time and enabled science applications;
- evaluating feasibility of embarking GNSS-R instruments in commercial aircraft while fulfilling requirements of the identified scientific applications;
- preliminarily designing a prototype GNSS-R instrument;

- defining a representative end-to-end demonstration.

The results of the activity will provide:

- confirmation of technical feasibility of embarking GNSS-based remote sensing instruments in commercial aircraft in order to complement Earth Observation satellite services;
- definition of requirements of airborne GNSS-R instruments for the identified scientific applications;
- requirements and accommodation constraints from aircraft manufacturers and carriers;
- identification of a significant use case, preliminary design of the related airborne GNSS-R instruments and definition of a representative end-to-end demonstrator.

Results from other ESA activities related to spaceborne GNSS-R will be duly considered and assessed, as well as from GSA studies (e.g. 'MISTRALE' project on airborne sensors for soil moisture measurements).

Funding required: €250k	*Duration:* 12 months	*ITT issue:* Q2 2019

4.3. Theme 3: Proof of concept of promising PNT Techniques and Technologies

Theme 3 forms the basis for future innovative PNT techniques and technologies by attracting the wider interest of the space and non-space industry in developing and testing new solutions.

As for previous Element 1 Work Plans, activities proposed here under Theme 3 range across diverse domains, addressing a wide variety of PNT techniques and technologies, with development of testing platforms which could be made available to industry for follow-on developments in NAVISP or in other programmatic frameworks at ESA or outside.

4.3.1. NAVISP-El1-029: Collaborative Processing of Distributed Receivers of Opportunity for Jamming and Spoofing Mitigation

The fast evolution of the Internet of Things (IoT), commercial Cloud platforms, and the future 5G standards are boosting development of new applications and technologies in the PNT field. Devices are expected to be increasingly connected to Internet in the next few years, storage and processing of data in the Cloud is already a reality, with 5G expected to bring very soon higher data rates and lower latencies to those devices than current 4G Long Term Evolution (LTE). Additionally, some mobile operating system provide an increasing access to raw measurements, including GNSS, WiFi and other sensors (as an example, Wi-Fi round-trip time is available in the first developer preview build of Android P).

In this context, the exploitation of GNSS signal snapshots and observables, together with other sensors' measurements and peer-to-peer communications, seems to constitute a feasible approach to enable new signal processing techniques. In particular, the collaborative processing of distributed receivers of opportunity (RoO) in close-by locations is a promising research area that could play an important role in the near future to solve some of the limitations faced by current GNSS receivers in the presence of jamming and spoofing attacks.

The main objective of the proposed activity is to design, develop and demonstrate innovative collaborative processing techniques for mitigation of jamming and spoofing attacks. The signals from multiple receivers of opportunity in close-by locations, together with the available peer-to-peer communications between them, as well as other signals of opportunity of interest, can be jointly exploited for detection and mitigation of jamming and spoofing attacks. These techniques can be implemented and assessed under controlled jamming and spoofing attacks. Representative user technologies and propagation conditions can be considered.

The proposed activity focuses on study and design of innovative collaborative processing techniques for mitigation of jamming and spoofing attacks. The developed techniques can be implemented in a software concept demonstrator and assessed in controlled laboratory conditions.

The tasks to be performed will include:

- consolidation of the state-of-art on jamming and spoofing detection, mitigation and localization;
- consolidation of requirements for the targeted use cases, in particular those relating to IoT, LBS and autonomous driving applications;
- identification of promising techniques based on representative receiver technologies for different use cases, including trade-offs based on simulations;
- preliminary design, implementation and validation of a software concept demonstrator.

The results of the activity will provide:

- a complete understanding of achievable capabilities of the proposed techniques and related detection, mitigation and localization performance of the engineered solutions, supported by trade-off analyses;
- a vision of how a more systematic approach to mitigation could benefit from cooperative processing;
- a software concept demonstrator, with associated results and user manual.

Results from related GSA activities (e.g. 'Advanced interference detection and robustness capabilities', Fundamental Elements) will be duly considered and the activity coordinated, in particular focussing on innovative concepts for spoofing detection not yet addressed.

Funding required: €400k	*Duration:* 12 months	*ITT issue:* Q3 2019

4.3.2. NAVISP-El1-030: Advanced Multi-Frequency Low-Cost High-Gain GNSS Antennas for next generation of Mass-Market Devices

Mass-market GNSS receivers, mostly installed in smartphones, use low cost antennas that need to be compatible with the communication antennas of these terminals. Typical antennas used in mobile phones are simple PIFAs (Planar Inverted-F Antennas) suitable for any constellation in L1 band, such as GPS/Galileo, GLONASS/Beidou. Their linear polarization (instead of circular) and low gain lead to several dB of signal loss. The antenna location is dictated by smartphone's design rather than RF constraints. This can result in sub-optimal locations where the interaction with user's hand further weakens the reception of GNSS signals. In case of highly irregular gain patterns, the relative loss is estimated at around 11dB compared to standard patch antennas.

New generation of mass-market devices includes flexible and wearable smartphones, which require development of advanced techniques and technology in terms of flexible materials for receiver antennas, in particular for the GNSS one.

Moreover, manufacturers are starting to move to multi-frequency (L1/(L2)/L5, E1/E5a) multi-constellation solutions allowing the usage of propagation correction techniques. This requires development of multi-frequency antennas and receivers, in order to take full benefit of these techniques.

In the best-case scenario of a fixed user with a clear view of the sky and without precise propagation correction (http://gpsworld.com/positioning-with-android-gnss-observables/), current mass-market single frequency antennas and receivers can attain horizontal positioning accuracies in the order of 7.5m (2σ). Positioning accuracy significantly improves down to 0.8m with mass-market dual frequency antennas, an order of magnitude better than current mass-market single frequency antennas. In a real mobile user scenario, improvements should be even higher in relative terms.

In case of indoor GNSS, the main challenges are high attenuation, multipath, and near-far effect. Novel high-gain antennas would be of high interest for enabling PNT applications in harsh environment. In particular, development of a multi-frequency, low cost, circularly polarized antenna with higher gain than current solutions available in the market would constitute a major breakthrough for these applications. In order to enhance positioning accuracy, carrier phase stability versus variation of antenna phase center should improve for any device orientation, together with reduction in number of cycle slips.

The main objectives of the proposed activity are to:

- study advanced techniques for miniaturization and radiation enhancement of GNSS antennas to be applied to design, manufacturing and testing of multi-frequency, low-cost, high-gain circularly polarized antennas for next generation of mass-market devices, including overall investigations on front-end, ADC (Analogue Digital Converter) and signal processing;
- identify solutions improving positioning accuracy and availability by means of advanced mass-market antennas and enabling innovative PNT applications in harsh environment.

The tasks to be performed will include:

- definition and consolidation of mass-market device requirements for indoor and outdoor applications. Evaluation of the mass-market challenges, opportunities and applications;
- state-of-the-art review of antenna concepts and technologies for single and multi-frequency GNSS mass-market antennas;
- investigation of techniques for miniaturization and radiation enhancement, including novel materials like Electromagnetic Band-Gaps (EBGs) or meta-surfaces that could also be applied to new generation of flexible/wearable smartphones;
- design of a device to be used as a mock-up for comparison between state-of-the art antennas and advanced ones (single and multi-frequency), considering new generation of flexible/wearable devices and their suitability for manufacturing;
- preliminary design of multi-frequency (in particular L1/E1 and E5a/L5) antennas, focussing on radiation performance, antenna phase center stability versus device orientation, accommodation in presence of other communication antennas;
- testing of GNSS mass-market antennas in static and dynamic configurations (both pedestrian and automotive dynamics, indoor and outdoor), of body masking effects and of changes to GNSS antenna pattern when the device is held.

The results of the activity will provide:

- a breadboard integrated into a receiver representative of a mass-market device;
  a roadmap for technological developments in support of next generation multifrequency mass-market antennas, including consideration of design manufacturability and target production costs.

Results from related GSA activities (e.g. ‘Multi-frequency Multipurpose Antenna for Galileo) will be duly considered and the activity coordinated.

Funding required: €450k	*Duration:* 12 months	*ITT issue:* Q3 2019

4.3.3. NAVISP-El1-031: Precise Timing for Indoor Small Cells

GNSS signals are widely used for time synchronization purposes in many different application sectors, including telecom, finance and energy. Telecom service providers, in particular, consider GNSS-based synchronization well adapted to macro-cells whereas alternative synchronization technologies (e.g. wire-based solutions like Precise Time Protocol) are deemed more suitable for indoor small cells, achieving timing accuracies in the sub-µs range depending on network topology.

Precise indoor time synchronization is expected to be of particular importance in future terrestrial telecom networks, where small cells are expected to populate indoor areas to provide 5G services, and tight synchronization requirements are needed for transmission of new 5G signals (in the order of 50 ns or below). Additionally, accurate time synchronization might also be of interest to allow accurate positioning based on ranging measurements derived from 5G signals.

GNSS signals can still be used in mild indoor conditions for positioning and timing applications at the cost of degraded performance due to high impact of deep fading and strong multipath (from Non-Line-Of-Sight components). In the particular case of timing applications, mass-market timing receivers are able to operate even with only one GNSS signal being tracked (if the receiver's position is a priori known) with expected accuracies in the order of 500 ns (1σ).

Lately, a new timing commercial service based on a low-earth orbit (LEO) constellation (i.e. Iridium) has become operational in order to provide an accurate alternative PNT in indoor conditions. In this case, the operator claims a timing accuracy of 100 ns (1σ) closer than GNSS to the most stringent requirements of telecom operators.

However, internal ESA activities have demonstrated that advanced antenna array processing techniques can achieve GNSS-based timing accuracies below 50 ns (1σ) in deep indoor conditions. The assessed techniques are fully compatible with low-cost antenna arrays that could be suitable for usage in small cells.

The objectives of the proposed activity are to:

- design, develop and demonstrate innovative GNSS-based time synchronization techniques enabling the exploitation of GNSS signals in small cells operating in indoor conditions;
- target time synchronization accuracies below 50 ns (1σ) enabling usage of GNSS signals for future applications with tight time synchronization requirements in indoor conditions, like future 5G indoor small cells;
- implement a breadboard for demonstration in representative indoor conditions of achievable timing accuracies based on the developed techniques.

The tasks to be performed will include:

- consolidation of state-of-the-art on GNSS timing and indoor GNSS signal processing, including exploitation of advanced array processing techniques;
- consolidation of requirements for the targeted use cases, in particular those relating to 5G small cells;
- identification of promising techniques at receiver level, including trade-off analysis based on simulations;
- breadboard design, implementation, lab validation and field demonstration in representative indoor conditions.

The results of the activity will provide:

- a complete understanding of achievable capabilities of proposed techniques and related timing performance;
- a breadboard, with demonstration of performance in indoor small cells.

Results from other related ESA activities will be duly considered and assessed, as well as those from EC studies on a potential future G2G timing service.

Funding required: €400k	*Duration:* 12 months	*ITT issue:* Q3 2019

4.3.4. NAVISP-El1-032: Advanced concept for chip-scale atomic clocks

Interest in compact and low power consumption atomic clocks (aka CSAC, Chip-Scale Atomic Clocks) have been progressively increasing in the last decade based on benefits demonstrated for a wide range of application, such as PNT in adverse environment (long coherent integration), secure telecommunication (frequency hopping) or in order to allow timing hold-over capability in case of loss of GNSS signal. Such devices feature the unique capability of a stable frequency (and timing) reference, otherwise unreachable with conventional technology based on quartz crystal resonators or MEMS oscillators.
Current CSAC technology rely on miniaturisation of atomic resonators by employing micro-fabricated vapour cells and on techniques to avoid usage of bulky and unscalable microwave cavities normally required in conventional atomic clocks. Such solutions have enormously reduced mass and power consumption, although still facing complexity in assembly and challenges in thermal design, given the need to operate vapour cells at high temperature. A number of recent publications have identified alternative advanced concepts for chip-scale atomic clocks (e.g. using solid-state materials as source of atomic resonator in place of vapour cells). These innovative concepts open new avenues in the miniaturisation, integration and power/thermal handling of such devices.

The main objective of the proposed activity is to identify, define and prove a novel approach for further miniaturisation, power reduction and integration of chip-scale atomic clocks.

The tasks to be performed will include:

- consolidation of state-of-art, patent survey and analysis of alternative approaches for miniature atomic clock resonators. This extensive survey shall cover the fundamental aspects of miniature atom sensing approaches, their practical realisation, the involved technologies and processes. This shall lead to the identification of the preferred solution for a proof-of-concept;
- definition, design, implementation and validation of a practical proof-of-concept demonstrator;
- test/demo campaigns and thorough assessment of results.

The results of the activity will provide:

- a proof-of concept demonstrator of solutions and technologies for chip-scale atomic resonators, using alternative materials in place of vapour cells;
- results of demonstration test campaigns with characterisation of key proof-of-concept performance parameters (e.g. stability, power consumption)

- recommendations for further miniaturisation, power reduction and integration of chip-scale atomic clocks, together with a plan for full technology development and industrialisation.

Funding required: €450k	*Duration:* 12 months	*ITT issue:* Q2 2019

4.3.5. NAVISP-El1-033: Antenna and Transponder Unit for Underwater PNT

Underwater wireless communications links have almost exclusively been implemented using acoustic systems. Optical links have proved impractical for many applications. Although underwater radio links were experimented in the pioneering days of radio, they did not meet the requirements of the time.

Given modern operational requirements and digital communications technology, the time is now ripe for using electromagnetic signals in the underwater environment.
Above 10kHz, electromagnetic propagation is more than a hundred times faster than acoustic. This has important advantages for command latency and networking protocols, where many signals have to be exchanged. Doppler shift is inversely proportional to propagation velocity, so is much smaller for electromagnetic signals.
Systems have already been proposed that function through use of a small unit that is most commonly hung from a dive boat or a larger unit buoy (the “GPS gateway”) with a pre-fixed transmitter at a fixed depth. The GPS gateway has a floating radio antenna in order to determine its exact location, and communicates with the wrist units via its underwater transducer portion. As a result of this communication, the wrist units know their range and bearing from the GPS gateway, as well as the exact position of the gateway. This allows the wrist units to calculate their own absolute position, independent of the position or motion of the GPS gateway. The gateway or the boat to which it may be attached is free to drift without affecting the position displayed. The position is displayed on the wrist-mounted screen, both as latitude and longitude values as well as a “dot”.

The main objective of the proposed activity is to design, manufacture and test a low cost / low profile antenna and transponder unit that performs well in a marine environment based on use of electromagnetic signals.

The tasks to be performed will include:
- definition of PNT requirements for on-surface and under-surface marine applications and definition/consolidation of antenna requirements;
- state-of-the-art review of antenna concepts and technologies;
- preliminary design of the antenna and associated front end;
- consolidation of evolutions of existing systems, as floating buoys ”GPS gateways”, based on innovative antenna design;
- manufacturing, underwater testing and development plan of the unit;
- assessment of benefits of Radio Frequency for underwater Communications/ PNT, integrating benefits of underwater sensor and on-surface sensors

hybridization platforms that can provide wide area availability to applications and services;
- trade off advantages and disadvantages of using RF signals, including GNSS repeater networks, in order to support PNT requirements of current and emerging underwater applications;
- analysis of requirements and constraints, for deployment of a RF-based system for wide area coverage for close to surface and under water applications;

The results of the activity will provide:
- solutions for low-cost, low-profile unit for underwater PNT;
- performance and cost/benefit assessments recommending innovative PNT applications to be enabled underwater.

Funding required: €450k	*Duration:* 12 months	*ITT issue:* Q3 2019

4.3.6. NAVISP-El1-034: AI-enabled baseband algorithms for High Fidelity Measurements

Critical applications such as autonomous vehicles and machine control require high fidelity raw measurements in challenging environments. In spite of significant progress made in recent years, for those applications GNSS performance remains unsatisfactory in terms of reliability in challenging environments, therefore requiring improvement.

The main challenges lie in handling transfer functions from baseband samples to high quality / high fidelity raw measurements (i.e. with minimal local environment impairments), which would then feed highly hybridized PNT engines such as those already available today (e.g., Kalman and particle filters, DPE, PPP/RTK).

Facing very challenging environments, the traditional approach reaches its limits when deriving algorithms from theoretical models and optimal estimates. Indeed, the targeted environments cannot be modelled properly and their changes cannot be predicted effectively (as new buildings, big vehicles obstructing the way towards key satellites to good geometry and generating multipath, variation in canopy coverage and thus attenuation along the year). Hence, prominent experts and academics in PNT technologies consider that the only way to design improved algorithms is to process real data collected in the field, learn from their behaviour and tune the algorithm accordingly. In the field of sensor fusion for autonomous driving, artificial intelligence (AI) and deep-learning processes are now involved to catalyse human engineering.

Meanwhile, AI-based capabilities are becoming more accessible, in particular thanks to key technologies made available in open source by major players in that field (Google, IBM, etc.). The GNSS community is collecting more and more raw data, including raw RF samples, worldwide, along with high quality reference trajectory: this may pave the ground for efficient machine-based learning processes.

In this context, artificial intelligence and machine learning can catalyse the empirical design process of baseband algorithms, fed by the ever-growing availability of real data collected by more and more users.

The objectives of the proposed activity are to:

- establish a new paradigm in the design of GNSS algorithms, leveraging on artificial intelligence and fed by collected data in field trials;
- design algorithm to provide high-fidelity raw measurements, along with quality indicators related to local environments.

The algorithm is intended to be designed based on AI and machine learning (e.g. open source), fed with massive data sets (such us raw GNSS measurements and samples available at ESA) and with new sets of opportunity data becoming available during the product's lifetime.

The tasks to be performed will include:

- consolidation of state-of-the-art in Artificial Intelligence and machine learning processes;
- definition of suitable AI architecture(s) for the GNSS baseband processor - one or more architecture depending on the result of the trade-offs;
- design and implementation of AI-based algorithms and associated learning processes;
- gathering and formatting data to feed learning processes and tune algorithms;
- field trials to test algorithms and assess preliminary performance;
- AI algorithms update, in order to complement learning with additional test data;
- Comparison of performance with state-of-the-art receivers.

The results of the activity will provide:

- innovative baseband algorithms, enabled by Artificial Intelligence, and able to provide high-fidelity GNSS raw measurements for applications operating in challenging environments;
- a breadboard implementing the AI-based baseband processor integrated with state-of-the art positioning engine;
- a machine-learning platform and environment.

Data and results from other ESA activities will be duly considered, assessed and used, as well as from GSA studies (e.g. 'ESCAPE' project for autonomous driving).

Funding required: €300k	*Duration:* 12 months	*ITT issue:* Q3 2019

4.3.7. NAVISP-El1-035: Machine-Learning to model GNSS systems

GNSS simulations are an important toolset supporting system engineering trade-offs and decisions. They are used to display and monitor key system performance indicators as well as study system behaviour, both through synthetic scenarios and real data replay.

Industry and ESA currently use different tools to simulate GNSS systems, however often constrained to undertake only one of two different options:

i) either an accurate, but computationally intensive and rather cumbersome approach is adopted to operate simulation chains representing each part of the system separately;
ii) or a much faster macro-model based tool is used, which has to be tuned and calibrated manually, however limiting its usability only to tuned scenarios.

Limitations of current macro model based tools can be overcome by training a machine-learning (ML) algorithm to predict the behaviour of the core of selected GNSS systems.

Trained on real data recorded during years of operation, the created ML tools shall be an intermediary product between the two above simulation approaches. With the user-friendly operability and low computational cost of current macro model tools, it shall aim at offering more accurate results on a wider range of different scenarios than a macro model, which otherwise would represent accurately only tuned scenarios.

Aside from absolute system performance, another important aspect in design decisions is system sensitivity to single factors, e.g. sensitivity to monitoring station positions. Advantages of using machine learning are the offered data analysis capabilities.

The main objective of the proposed activity is to assess usability of machine learning (ML) techniques in support of GNSS system simulations by modelling selected system segments using ML algorithms

The tasks to be performed will include:

- review of state-of-the-art in the field of Supervised Learning techniques for Multi-Target prediction, trading-off different ML techniques;
- training of the machine learning algorithms selected during trade-off analyses on observables as input and final orbit products as output data for at least two GNSS cases (e.g. IGS, augmentation systems or others);
- assessment of algorithm's performance on previously selected test data sets;
- identification of main issues in using ML to model GNSS behaviour.

The results of the activity will provide:

- demonstration of usability of ML to model segments of a GNSS system;
- implementation of selected ML techniques into tools to simulate GNSS system segments capabilities and behaviour.

Funding required: €250k	*Duration:* 15 months	*ITT issue:* Q3 2019

4.3.8. NAVISP-El1-036: Precise positioning for mass-market: optimal data dissemination demonstrator

Until recently, RTK and PPP technologies have been developed for professional applications, the price not being affordable for mass-market users. Over the last couple of years, however, impressive breakthroughs have been witnessed for mass-market applications. While multi-band GNSS will provide an improved user experience in many consumer settings, the solution alone cannot deliver sufficiently robust and accurate performance to meet the stringent accuracy requirements of automotive and industrial applications, unless paired with accurate GNSS techniques. A potential way forward could consist in a concept that leverages on the latest breakthroughs in GNSS technology and future terrestrial wireless networks to broadcast multi-GNSS augmentation services in real-time at low cost.

Today, GNSS corrections are provided to users either via satellite broadcast or via IP mobile sessions. Almost 15 years ago, BKG released the NTRIP protocol (Networked Transport of RTCM via Internet Protocol), an open non-proprietary protocol designed to distribute the GNSS streaming data to a stationary or mobile receiver over the Internet. NTRIP consists of two pieces of software, which communicate over the internet, one at server side (NTRIP Caster SW), and one at the client side (NTRIP Client SW). An important factor that contributed to NTRIP's success is its adoption of existing internet standards. It was developed based on the ubiquitous HTTP and TCP paired with usage of port 80 commonly used by web servers around the world.

Although the NTRIP dissemination works quite well, the TCP is a protocol for communication between exactly two endpoints (each characterised by a globally unique IP address) and HTTP is a standard unicast application. In other words, the existing approach adopted in the GNSS community has limited scalability and thus, poses some limitations to the mass-market applications. Now, imagine the challenges for the correction service providers if tens of thousands of devices are simultaneously requesting a response. This would be difficult to establish due to increased overhead. Under this scenario, terrestrial broadcast via cellular signals (i.e. pure downlink) could fit the operational concept much better because it would allow the MNO (mobile network operator) to transfer data based on a "*Send-to-All''*-like dissemination. Other approaches like the use of DAB could be also considered for broadcast. With this approach, serving many users is expected to be beneficial, i.e. the corrections stream is generic and applicable to all users within the cell, which means that wireless network radio resources are not wasted and costs are reduced.

Terrestrial networks are continuously targeting evolutions of broadcast technology, mainly for audio and video content (e.g. Multimedia Broadcast Multicast Service technology). The idea is to allocate a portion of the wireless network resources to host specific content, enabling a MNO to send a single data stream to all mobile users in a particular area rather than having to send an individual stream to each user. This specific content could be related to high-accuracy GNSS assistance data and indeed support to multi-GNSS positioning techniques have been included in the list of use cases that target future terrestrial wireless networks. The potential opportunity for the

GNSS community is huge, however there is no implementation of such innovative terrestrial broadcast concept, pilot or commercial, yet.

The objectives of the proposed activity are to:

- develop a demonstrator to leverage on terrestrial broadcast technologies as means to provide mass-market users with high-accuracy multi-GNSS data (e.g. RTK, N-RTK, PPP);
- prove an end-to-end terrestrial broadcast service concept in real operational scenarios and environments (e.g. PPP for a vehicle on highway);
- demonstrate the overall cost reduction when using cellular signals or other broadcast mechanisms instead of unicast data links over IP networks.

The tasks to be performed will include:

- reviewing, identifying, and consolidating a list of preliminary requirements and use cases;
- providing a preliminary list with COTS equipment readily available to be included in a testbed and a preliminary list of HW and SW that needs to be developed during the activity;
- defining a test bed architecture (functional, logical, and physical) by leveraging on existing open standards for mobile wireless networks, infrastructure for terrestrial broadcasting and third party RTK service providers;
- selecting a third party RTK service provider (commercial or public agency), a COTS GNSS receiver, a broadcast technique and COTS HW and SW relevant for a terrestrial network architecture;
- SW algorithms development for coding and decoding data streams provided via cellular signalling by terrestrial networks;
- testbed integration, encompassing laboratory validation for connectivity, communications and decoding of information streams;
- field trials definition and execution.

The results of the activity will provide:

- a novel testbed to demonstrate terrestrial broadcast of high-accuracy multi-GNSS assistance data via cellular signals (i.e. RF signal bands used in mobile telecommunication);
- feasibility of the identified concept, with insight in the main system level trade-off’s; impact assessment on users expectations.

Funding required: €350k	*Duration:* 12 months	*ITT issue:* Q1 2019

4.3.9. NAVISP-El1-037: PNT Timing & Synchronisation for Aviation Systems and Networks

GNSS is extensively used in aviation, notably for:
- positioning and timing for on board navigation purposes;
- timing and synchronisation for datalink communications (board to ground and viceversa);
- timing and synchronisation on ground for Surveillance, Air Traffic Control (ATC) and communication networks.

GNSS time outages or unexpected anomalies may affect aviation systems and networks. The advent of multi-frequency multi-constellation GNSS time information may provide a more robust timing and synchronisation service in aviation. Yet, usage of time information from multiple GNSS is subject of research and is not yet standardised.
At the same time, other and independent timing sources may be available to back-up/complement the GNSS timing and synchronisation service, e.g. clocks, Low Frequency systems, Network Time Protocols (NTPs). Their usage may depend on various factors, mainly coverage area and phase of flight for the on board case, ground equipment for surveillance and communications.
According to aviation stakeholders, in order to progress towards a safer Air Traffic Control it is of high importance to:
- perform an assessment of criticality of GNSS timing in aviation and role of non-GNSS complementary/back up timing sources;
- identify innovative schemes involving various PNT sensors to improve robustness and security in the timing and synchronisation service for aviation systems and networks.

The objectives of the proposed activity are to:
- assess the criticality of the use of GNSS time in aviation;
- define and perform demonstration of innovative PNT concepts complementary to GNSS, in order to provide robust and secure timing and synchronisation services for aviation systems and networks.

The tasks to be performed will include:
- a thorough review and description of the systems (and networks) in aviation using GNSS time on board and on ground;
- identification of required timing and synchronisation performance for aviation systems and networks;
- identification of the main threats / external factors that could affect specifically the usage of GNSS time;
- identification of timing technologies/sensors (complementary to GNSS, e.g. national LF systems) that are used in aviation (separately on board and on ground) and meet the required timing and synchronisation performance;
- a thorough review and definition of alternative timing technologies/sensors that could be used as a GNSS time back-up/complement in aviation systems and networks (separately on board and on ground);
- definition of relevant use cases with relevant stakeholders to be considered for the provision of robust timing and synchronisation services in aviation system and networks ;

- definition of innovative schemes with PNT sensors for each use case, with assessment of achievable performance, benefits and feasibility;
- demonstration of PNT innovative schemes as defined above, through either simulation or other means to be proposed.

The results of the activity will provide:
- development and demonstration of innovative and robust PNT schemes for timing and synchronisation in aviation systems and networks, on board and on ground, along with achievable performance and feasibility.
- recommendations for aviation (CNS/ATM).

Data and results from other ESA activities will be duly considered, assessed and used, as well as from EC and GSA studies (e.g. 'EGALITE' project for definition of a GNSS timing service concept and Fundamental Element project on GNSS Timing Receiver for Critical Infrastructure).

Funding required: €250k	*Duration:* 12 months	*ITT issue:* Q2 2019

5. SUMMARY

Activity funding & duration	Funding required (€k)	Duration (months)
Theme 1		
NAVISP-El1-027: Alternative Space-based PNT Data Layer	250	12
Theme 2		
NAVISP-El1-028: GNSS Science with Commercial Aircraft	250	12
Theme 3		
NAVISP-El1-029: Collaborative Processing of Distributed Receivers of Opportunity for Jamming and Spoofing Mitigation	400	12
NAVISP-El1-030: Advanced Multi-Frequency low-cost high-gain GNSS antennas for next generation of mass-market devices	450	12
NAVISP-El1-031: Precise Timing for Indoor Small Cells	400	12
NAVISP-El1-032: Advanced concept for chip-scale atomic clocks	450	12
NAVISP-El1-033: Antenna and Transponder Unit for Underwater PNT	450	12
NAVISP-El1-034: AI-enabled baseband algorithms for High Fidelity Measurements	300	12
NAVISP-El1-035: Machine Learning to model GNSS systems	250	15
NAVISP-El1-036: Precise positioning for mass-market: optimal data dissemination demonstrator	350	12
NAVISP-El1-037: PNT Timing & Synchronisation for Aviation Systems and Networks	250	12
Total	3800	

El1 ID	Activity Title	2019				2020				2021			
	Theme 1												
027	Alternative Space-based PNT Data Layer		ITT										
	Theme 2												
028	GNSS Science with Commercial Aircraft		ITT										
	Theme 3												
029	Collaborative Processing of Distributed Receivers of Opportunity for Jamming and Spoofing Mitigation			ITT									
030	Advanced Multi-Frequency low-cost high-gain GNSS antennas for next generation of mass-market devices			ITT									
031	Precise Timing for Indoor Small Cells			ITT									
032	Advanced concept for chip-scale atomic clocks		ITT										
033	Antenna and Transponder Unit for Underwater PNT			ITT									
034	AI-enabled baseband algorithms for High Fidelity Measurements			ITT									
035	Machine Learning to model GNSS systems			ITT									
036	Precise positioning for mass-market: optimal data dissemination demonstrator	ITT											
037	PNT Timing & Synchronisation for Aviation Systems and Networks		ITT										