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EUROPEAN SPACE AGENCY

NAVIGATION PROGRAMME BOARD

NAVISP Element 1 Work Plan for 2021

Subject

This document presents the NAVISP Element 1 Work Plan 2021 activities.

Required action

The participating States in NAVISP Element 1 are invited to approve, by simple majority, the Element 1 Work Plan for 2021.

Voting rights and required majority

Simple majority of the Participating States in the Element 1 of the NAVISP Programme (AT, BE, CH, CZ, DE, DK, FI, FR, GR, HU, IT, NL, NO, RO, SE, 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 2021.

2. PREPARATION OF NAVISP ELEMENT 1 WORKPLAN FOR 2021

Notwithstanding difficulties for external interactions due to the Covid-19 crisis, the Executive has again applied the well proven ‘funnel scheme’ to collect the most promising proposals for the Element 1 Work Plan for 2021.

In reverse order with respect to previous years, first the Executive has collected external inputs, mainly from NAVAC, and then has complemented and refined them through an ESA-wide consultation with the ultimate purpose to populate the work plan according to well-established guidelines.

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 2021’ (ESA/PB-NAV(2020)16) presented at the 115^{h} PB-NAV meeting.

3. STATUS OF COORDINATION

The Element 1 Work Plan for 2021 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.

In particular, the activity ‘Proof of concept of common test procedures and approaches to assess robustness of civil GNSS receivers’, previously presented in the draft version of the work plan, has been withdrawn in order to take into account comments received from EC and GSA. Indeed after a thorough discussion with all the market segment leaders, EC and GSA had concluded that there was overlapping with on-going and planned EC and JRC activities.

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.

Element 1 is basically the exploratory component of NAVISP, and the innovative and disruptive nature of the idea is what matters. New solutions (systems, equipments, products, algorithms, techniques, technologies) are generated and their feasibility is assessed, tested and demonstrated, with recommendations for follow-on activities.

Currently, Element 1 nature, size and participation does not allow to cover organically most of the recommended follow-on developments (e.g. to increase the TRL of the demonstrated innovative solution), unless this is brought forward by industry in Element 2 or national institutions in Element 3.

In the selection process, priority has been given to Proof-of-Concept of promising PNT solutions in order to progress from low TRL activities to marketeable products by industry in follow-on phases, or to be further carried out by the public sector in the most appropriate programmatic framework.

Upon NAVAC recommendation, proposals within the following four areas were encouraged:

- Autonomous Transport and Green Mobility;
- Seamless PNT applications for Industry 4.0, e.g. for indoor infrastructure logistics;
- Alternate PNT timing, alternative or complementary to GNSS;
- PNT Robustness and resilience.

The activities proposed in the 2021 Work Plan have been grouped according to the same innovation categories as last year, i.e. New or Existing Technology and New or Existing Market.

4.1. Category 2: New Technology / Existing Market

4.1.1. NAVISP-El1-052: Robust navigation of airborne autonomous systems with carrier phase of ARNS signals

As the Unmanned Aerial Vehicle (UAV) regulatory framework continues to evolve towards autonomous flight and operations beyond visual line-of-sight (BVLOS), it drives the need for reliable navigation services to complement or act as a back-up to existing ones. Trusted PNT solutions have to be developed to help tackle the many challenges that a congested airspace brings such as the safety of autonomous flight in populated areas or in-flight collision avoidance. Moreover, it is paramount to support future UAV Traffic Management (UTM) systems with the tools for safe operations. Regulating bodies will require reliable trajectory information in the decision making process and for conveying information, such as changes in the flight route to the UAV, in a timely manner with sufficient reliability.

In the search for robust and resilient positioning alternatives, users have already looked at signal-of-opportunity (SOOP) techniques that make use of radiofrequency signals broadcasted for different purposes (e.g. wireless, TV, etc.). These signals are more robust against interference and spoofing and can contribute to Position, Navigation and Timing (PNT) determination. So far, SOOP-based positioning solutions have not achieved targeted accuracy levels for UAV operation, nor have they proven to be suitable for integration in safety-critical processes. Nevertheless, in recent studies, the feasibility of using carrier phase positioning techniques has been demonstrated over the cellular networks. Therefore, it is envisaged that similar techniques could also enable high-accuracy alternative PNT solutions for UAV, if they are based on reliable and certifiable signals-of-opportunities such as the Aeronautical Radionavigation Service (ARNS) signals.

In order to use ARNS signals in safety-critical UAV operations such as autonomous landing, take-off and BVLOS navigation, one would also have to be guaranteed on a certain level of trust in the PNT solution and be provided with timely alerts when the criticality threshold is exceeded. Although the consolidated knowledge on safety cases and feared events for UAV operations is not yet mature, the precise characterisation (e.g. position and clock parameters) of ARNS transmitters could facilitate the definition of integrity, integrity risks, and integrity monitoring concepts.

The objectives of the proposed activity are to:

- define and implement robust and reliable PNT concepts for autonomous navigation of UAVs, relying on carrier phase of ARNS signals further hybridized with dead-reckoning (e.g. inertial measurements) and vision (e.g. terrain mapping). The foreseen SOOP in ARNS bands would primarily be VOR and ADS-B signals;
- develop a SDR-based proof-of-concept to demonstrate feasibility of the proposed techniques on real signals,

- validate several related hypotheses in specific beyond visual line of sight (BVLOS) operation conditions.

The tasks to be performed will include:

- identification of regulations and technical challenges of BVLOS operations of UAVs;
- derivation of performance targets for accuracy, integrity, continuity, availability and latency;
- Development of reliable PNT concepts and algorithms based on SOOPs and similar technologies, hybridised with dead-reckoning, in support of integrity protection in UAV operations;
- Implementation of a SDR platform for receiving and processing terrestrial ARNS signals suitable for UAV platforms and for deriving the raw observables for PNT;
- Demonstration of the concept with real signals representative for connected drones operating in BVLOS conditions;
- benchmarking with state-of-the-art and assessment of the improvements of ARNS carrier phase solutions, in particular for BVLOS operations.

The main results of the activity will provide:

- a preliminary assessment of integrity concept and safety aspects for the purpose of reliable navigation with ARNS signals, as a complementary radio-based positioning technique, for UAVs operating under BVLOS;.
- Design and implementation of ultra-reliable overall PNT concept and algorithms in support of safety in UAV operations;
- SDR receiver platform for processing ARNS signals;
- Implementation of processing algorithms used to derive the raw observables, a PNT solution, and for triggering alerts;
- Test reports, including achievable performance, for both synthetic (laboratory) and real signals conclusions.

Funding required: €600k	*Duration:* 18 months	*ITT issue:* Q3 2021

4.1.2. NAVISP-El1-053: Real-time Big Data Processing for GNSS Integrity

Different user communities defines and adopts their specific PNT integrity concepts. The relevance of GNSS integrity is evolving and increasing to support the most sophisticated PNT solutions in different market segments.

Today, a number of GNSS integrity concepts is in use (e.g. RAIM, SBAS) or under development (ARAIM). Yet, all existing integrity concepts have important limitations to protect users in specific local environments. Techniques like RAIM and ARAIM have limitations in harsh local environments, as performance is very sensitive to the loss of tracking of satellites by the user. SBAS techniques are less sensitive to the loss of tracking, but they do not provide integrity information related to the local user environment.

The above limitations have triggered reflections for an innovative solution, here proposed as “Real-time Big Data Processing for GNSS Integrity”.
In this concept, user receivers provide data to a Central Processing Facility (CPF). The CPF uses these data to compute not only global integrity products (overbounding satellite orbit and clock errors) but also local ones (overbounding local errors, e.g. multipath, interference, ionosphere).

On the one hand, it is recognized that the typical quality of user receiver data is lower than the one from fixed integrity monitoring stations, like SBAS RIMS data. On the other hand, the number of GNSS-users is significantly higher than the number of fixed integrity monitoring stations (billions of GNSS-users in the world versus 50 RIMS maximum for a typical SBAS infrastructure). From preliminary analyses, it seems that this very large amount of user data can provide integrity products of very high quality, with the additional feature of computing local integrity products.

Therefore, the main objective of the proposed activity is to demonstrate the feasibility of a new concept to compute global and local integrity data in real time based on big-data collected form GNSS user receivers. This concept may be of interest for various user-groups for integrity applications well beyond civil aviation.

The tasks to be performed include:

- development of prototype CPF algorithms based on user data;
- simulation of data in various scenarios, e.g. large number of user receiver data with unknown user position and with varying level of multipath and signal blockage;
- assessment of the need to maintain a very small number of fixed integrity monitoring stations (e.g. to detect common mode failures);
- computation and trade-off of global and local integrity products;
- preliminary selection of communication channels and assessment of impact on performance (e.g. Time-To-Alarm, availability).

The main results of the activity will provide:

- a feasibility assessment of this new integrity concept based on real time processing of big data from a multitude of GNSS user receivers;
- comparative analysis of benefits and drawbacks, trading off this new concept with existing ones, as SBAS and RAIM, or under development, as ARAIM.

Funding required: €300k	*Duration:* 12 months	*ITT issue:* Q2 2021

4.1.3. NAVISP-El1-054: Monitoring timing signals from space. A novel approach for a worldwide robust time and synchronisation capability

Many systems (including critical infrastructure) rely on GNSS receivers for synchronization purposes nowadays, for instance telecom networks, power grids and financial markets. Due to the vulnerability of GNSS to interference and spoofing, there is a growing need on alternative (non-GNSS-dependent) timing services, as shown by several investigations and initiatives on this topic (e.g. European Radio Navigation Plan, experimentations under the initiative of US Departments of Transport).

The use of terrestrial transmitters (e.g. cellular signals, SOOP, eLoran, Digital TV) as timing alternatives to GNSS has already been considered and demonstrated. However, despite good robustness and coverage, including indoor, these options share a strong limitation when it comes to resilience: they all mostly rely on terrestrial GNSS receivers to create the reference time source, which may be interfered or even spoofed.

The use of terrestrial transmitters to distribute timing and synchronisation requires finding an efficient workaround to GNSS reference stations on ground, without requiring the deployment of additional ground infrastructure, which would be very expensive and long to deploy if the provision of a worldwide service is targeted.
An attractive workaround to the above issue could be to transfer the referencing function into orbit, leveraging on the enhanced resilience of GNSS space receivers and the ability to monitor terrestrial signals from space.

LEO satellites have been already shown to be able to monitor signals from non-cooperative ground transmitters in order to estimate their location. This concept can be extended to estimate the clock offsets of terrestrial transmitters in order to synchronise them. Thanks to their wide coverage, multiple receivers can be simultaneously synchronized. An on-board GNSS receiver will still need to be used, but being at LEO altitude it will be robust to interference originating from terrestrial sources and benefit from additional space sources to enhance further the resilience of the on-board time reference and its link to UTC (e.g. using EDRS, satcom, ISL).

The objectives of this activity are to:

- study a novel system concept for the provision of accurate and resilient timing, relying on terrestrial RF transmitters (Digital TV) synchronized to GNSS using space monitoring infrastructure;
- investigate optimal architectures and implementation, in particular for the space monitoring functions;
- validate performance in terms of achieved accuracy and resilience; accuracies in the order of at least micro-seconds and lower shall be targeted.

The tasks to be performed include:

- identification of the most suitable techniques for the proposed concept (techniques for monitoring terrestrial signals from space, use and processing of SOOP for timing purposes);
- identification and analysis of architectures, techniques and technologies for the candidates solutions, in particular for the space-based monitoring component (including constellation sizing, coverage, targeted accuracy, payload and algorithms), trading-off different options and end-to-end performance;
- implementation and simulation of the critical processing algorithms used for signal monitoring, synchronisation, and validation of the associated models and performance using real signals;
- assessment of timing performance achieved for the end-user with different architectures and techniques, via simulations;
- definition of a detailed proof of concept and assessment of a potential future demonstrations.

The main results of the activity will provide:

- a feasibility analysis of the proposed concept, including trade-off's and a high-level system architecture;
- simulation results of critical algorithms associated to an end-to-end performances analysis;
- initial definition of future demonstrations.

Funding required: €450k	*Duration:* 12 months	*ITT issue:* Q3 2021

4.1.4. NAVISP-EL1-055: Attitude control of autonomous ships navigating in ports

One of the many new emerging concepts having the potential to address present and future maritime challenges is autonomous ship navigation. In particular, the concept is expected to allow for more efficient and competitive ship operations while reducing, at the same time, vessels' environmental impact.

Several activities have been initiated in the recent years with the aim to jumpstart the concept of autonomous shipping. The EC project MUNIN (Maritime Unmanned Navigation through Intelligence in Networks) aims at developing and verifying a concept for an autonomous ship. The AAWA project was started to develop specifications and possible design for the next generation autonomous ships. UTOSEA is a collaboration to develop technology and knowledge for automated situational awareness for ships. All these projects and others have been looking at the concepts or technologies needed for autonomous shipping to become a reality.

On ESA side, several exploratory activities have been launched with relevance to autonomous vessels. The GSP activity MAGS (Maritime Adaptive GNSS Safety Concept) has studied a novel safety concept to be used in the vicinity of ports, which makes use of an Adaptive Alert Limit (AAL) by creating a centralized port monitoring and processing function for all vessels in port waters, instead of using a fixed Alert Limit (AL). Moreover, one of the key aspects of the MAGS concept is the consideration of the vessel not as a single point but as a full 3D body, considering both position and attitude, taking into account the real ship contour and defining a marine vessel protection area (MVPA).

Two parallel NAVISP contracts (Artificial Intelligence / Machine Learning for Autonomous Vessels) are studying the usage of these techniques applied to specific autonomous operations (port approach, auto-docking and others). In particular, different configurations of PNT sensors are being investigated (GNSS plus vision, infrared, LIDAR, depth sensors) in combination with AI techniques to improve performance and resilience of maritime PNT solutions.

Moreover, other ESA activities have studied the maritime multipath environment and the results can be leveraged to propose better optimized antenna systems including the possibility of multi-antennas or adaptive ones for multipath mitigation and attitude determination.

While these activities are providing great steps in the direction towards autonomous vessels, they are looking into enabling building blocks and not yet a complete integration.
The proposed activity is a proof-of-concept, testing these methods and techniques in real scenarios in order to bring the PNT technology forward. Focusing also on attitude determination and control will allow testing a comprehensive set of solutions, techniques and technologies for autonomous operations in different scenarios.

The objectives of the proposed activity are to:

- develop and prove alternative PNT concepts for ship positioning and attitude in ports, assessing achievable level of performance;
- define attitude control based on different configurations of actuators and sensors that correspond to different class of vessels (e.g. ferries, tankers, containers, fishing vessels, tugs);
- use several GNSS receiving (adaptive) on-board antennae and sensors (e.g. AI-NAV) to support ship attitude determination;
- develop a proof-of-concept prototype to be tested in port scenarios.

The tasks to be performed include:

- analysis of performance requirements applicable to the autonomous navigation of vessels at port, including attitude determination;

- assessment of achievable PNT performance levels achievable, including accurate and reliable attitude determination, considering fusion of GNSS data with IMU sensors typically available on-board;
- proposals for alternative PNT concepts potentially based on the use of multiple GNSS receiving antennae (including adaptive antennas and potentially distributed over the vessel) and sensors (e.g. AI-NAV) on board to help determining the ship attitude and in new integrity concepts (e.g. MAGS).
- Develop a proof-of-concept prototype to be tested in port scenarios.

The main results of the activity will provide:

- different alternative PNT concepts and technical solutions for present and future autonomous maritime vessels;
- a prototype autonomous navigation PNT receiver based on COTS elements testing the methods and techniques identified in selected maritime operational scenarios

Funding required: €600k	*Duration:* 18 months	*ITT issue:* Q4 2021

4.1.5. NAVISP-EL1-056: Advanced algorithms and techniques for resilient time provision

Market trends show a clear increase in number of timing-dependent services (including highly critical ones), with increasing demand for improved performance and capability. RF signals broadcasting is becoming increasingly dependent on GNSS for accurate timing and frequency references. 5G networks will be increasingly dependent on precise and robust timing and synchronisation. Integer timing signals are essential to keep communication systems and information systems synchronised, while providing a frequency reference for radio systems. Other market segments include the power industry, operating widely distributed infrastructure with stringent timing and availability requirements to improve the efficiency of power generation and distribution, and finance corporations that are also operating critical infrastructure deployed worldwide, with rapidly evolving practices (e.g. high-frequency trading) and associated regulatory constraints.

In these market segments today, GNSS remains the prime source of time information for system synchronisation. In order to improve resilience of time provision and cope with GNSS vulnerabilities, different combinations of alternative time sources can be used (e.g. local clock to guarantee hold-over, packet-based time protocols, or any other signal of opportunity).

Combining different time sources call for advanced techniques and algorithms to provide the required level of time performance to users. In addition, the availability of such robust algorithms shall allow the various providers of timing solutions to monitor their network or technology for fault detection and system optimisation.

One of the possible solutions could be based on combined time and frequency Kalman filters applied to multiple sources of time. Although the idea of a frequency Kalman was introduced long ago, there is no trace in the literature of any real application to date, most probably due to the problem of steering to an external time reference, which is better solved in the time domain. The idea of optimizing Kalman parameters around some natural resonance frequency has both intuitive and strong physical meaning while, in contrast, setting optimum Kalman parameters to minimize the time error seems quite artificial and has no analogous physical meaning. Other solutions also include various types of Machine Learning techniques, which could also be combined with the Kalman filter approach.

The applicability of these techniques could be very broad, from time service providers for critical infrastructure and network operators to trade organisations, oil and gas companies, scientific research, power grids' corporates, etc., at different scales and based on the available time information sources for each of them.

The objective of this activity is to analyse and develop advanced techniques and algorithms for the generation of a resilient time reference based on a multiplicity of time sources (e.g. local clocks, GNSS, signals of opportunity). In particular, algorithms based on hybrid (frequency-time) Kalman filters, Machine Learning techniques shall be considered, as a minimum.

The tasks to be performed include:

- review and trade-off analysis of algorithms and techniques for generation of a time reference based on a multiplicity of time sources and information;
- development of algorithms and techniques for optimum combination to reach the targeted accuracy, stability, continuity and availability requirements;
- preparation of an experimentation plan for the assessment of the benefits of such combinations as compared to state-of-the-art solutions;
- tuning algorithms, including an exploration of ways to use AI to adapt the thresholds of the corresponding frequency and time Kalman detection barriers;
- carrying out extensive experimentation over a sufficiently representative set of data in order to properly assess performance of algorithms;

The main results of the activities will provide:

- advanced techniques and algorithms for the generation of a resilient time reference, including detailed processing models;
- outcome of extensive experimentations to assess performance and capabilities;
- Hardware to operate and collect time information data.

Funding required: €400k	*Duration:* 18 months	*ITT issue:* Q2 2021

4.2. Category 3: Existing Technology / New Market

4.2.1. NAVISP-El1-057: Development of advanced VDES-R user technologies for alternative PNT

VDES (VHF Data Exchange System) aims at digitalising maritime communications and enable the introduction of new capabilities for a variety of maritime use cases, such as AIS and Search and Rescue. It is also being considered to support alternative PNT with a dedicated ranging capability, the so-called R-mode or VDES-R, which is currently being investigated. The initiative is supported by IALA (International Association of Marine Aids to Navigation and Lighthouse Authorities, previously known as International Association of Lighthouse Authorities).

Through activities in Element 1 and 3, NAVISP is carrying out activities towards resilient PNT solutions for maritime applications. Investigations carried under Element 3 MARRINAV activity have confirmed VDES-R as a very relevant alternative source of PNT information, in combination with GNSS and eLoran. The VDES-R capabilities could be further enhanced by leveraging advanced user technologies, which would work around the limited bandwidth allocated to VDES channels and benefit accuracy and integrity performance, and security. This is foreseen, for instance, by tailoring advanced positioning and signal processing techniques to VDES-R, such as carrier phase positioning, advanced multipath mitigation, channel and antenna diversity processing. Additionally, ranging signals can potentially be used in combination with the bidirectional data channel in order to enhance resilience against spoofing attacks.

Initial guidelines and recommendations for VDES via satellite (VDE-SAT) are emerging. According to ITU – M.2092: ‘*Due to the frequency used, it is likely that VDE-SAT will consist of LEO or MEO satellites. VDE-SAT could also consist of hosted payloads on spacecraft in such orbits*’.

In the framework of ESA’s Open Space Innovation Platform (OSIP), the ANGELOS study is preliminary investigating the concept of using R-mode for VDE-SAT based, in particular, on a Low Earth Orbit (LEO) constellation using CubeSats. Detailed analyses are required to address complementary technologies at user level for VDE-SAT.

The objectives of this activity are to:

- investigate and prove the concepts of novel user segment technologies allowing enhanced positioning with VDES (accuracy, integrity, security) and complement ongoing VDES investigations to improve APNT capabilities for coastal use cases;
- analyse synchronisation/timing issues for R-Mode;
- assess compatibility with a VDE-SAT service provided from MEO or LEO satellites.

The tasks to be performed include:

- identification of relevant use cases and scenarios (e.g. involving an hybrid terrestrial/satellite VDES)
- study of enhanced architectures, techniques and technologies, small to very small form factor VHF antenna, advanced signal processing for multipath mitigation and carrier phase tracking, positioning leveraging carrier phase of VDES signals;
- implementation of the identified solutions into breadboards to prove the concept of those user technologies in trials representative of different use cases and scenarios;
- execution of field trials, and benchmarking with state of the art (conventional VDES R-mode, GNSS, eLoran)

The main results of the activity will provide:

- breadboards implementing the proof-of-concept of VDES-R user technologies (e.g. user terminal with antenna, RF, baseband and navigation algorithms).
- results from field trials (demonstration and benchmarking)
- recommendations and roadmaps for follow-on activities.

Funding required: €700k	*Duration:* 18 months	*ITT issue:* Q2 2021

4.2.2. NAVISP-El1-058: Demonstration of GNSS position bounding using satellite uplinks

The number of miniaturized devices with satellite connectivity (e.g. asset trackers) is quickly growing, and with this, the need arises to provide reliable positioning information to those resource-limited devices. This is particularly relevant in growing asset tracking and user-charging use cases, in many sectors such as in railway (wagons and containers tracking), maritime (VMS, container tracking) and road (road-tolling).

Because of the open and broadcasted nature of Global Navigation Satellite System (GNSS) signals and the physical and hardware constraints of these tracking devices (size, energy consumption, duty-cycled operations in un-trusted conditions), traditional Position, Velocity and Time (PVT) assurance solutions cannot be easily employed if solely based on GNSS,.

Satellite constellations may support device localization using the uplink signal. Even though sporadic and not very accurate, the determined location may be considered trustworthy, as it is performed by the system. It could therefore be used to bound the device's position to a certain area, and this solution is especially advantageous for hardware platforms with limited energy resources and computing power. Uplink positioning shifts the processing burden from the user equipment to the infrastructure, where it can benefit from increased computational resources and advanced signal processing techniques. Moreover, PNT solutions computed by the infrastructure are less susceptible to threats such as spoofing and jamming. Masking or meddling with the device's transmission will deny the service rather than tamper with it. As a result, uplink positioning enables context awareness and grants the user a certain level of protection against malevolent parties.

The combination of accurate GNSS measurements with trusted, but less accurate, uplink measurements is an attractive concept to secure PVT. In the ever growing world of navigation services, it is paramount to toughen and augment GNSS-based positioning services.

The objectives of the activity are to:

- assess and demonstrate the feasibility of using satellite uplink measurements for position bounding;
- investigate architectures and algorithms for enhancing trust of PVT by combining information derived from GNSS signals with satellite uplink measurements, and using the security aspects of the uplinks PVT solutions;
- assess, in particular, improvements achieved by the identified solutions in terms of security / resilience / trust of the resulting PVT;
- analyse application for specific use cases, as tracking railway wagons and containers/ maritime vessels, containers and oceanographic buoys (e.g. using VDE-SAT for uplink)

The tasks to be performed include:

- identification of promising techniques and perform trade-off analysis;
- assessment of the technical capabilities and limitations of current COTS components in supporting this technique;
- feasibility analyses of the use of satellite uplink for PVT assurance in asset tracking;
- design and development of PVT assurance architectures and algorithms based on the aforementioned concepts;
- validation of the proposed solutions by means of simulations, laboratory tests and using measurements derived from existing uplinks;
- benchmarking with state-of-the-art and assessment of achievable performance and security levels.

The main results of the activity will provide:

- feasibility assessment and test results of a trustworthy and cost-efficient positioning service for remote nodes with limited connectivity;
- breadboards (e.g. user equipment, satellite emulator);
- roadmap towards prototyping, paving the way for industrial products, for instance through initiatives in NAVISP Element 2.

Funding required: €450k	*Duration:* 18 months	*ITT issue:* Q3 2021

4.2.3. NAVISP-El1-059: Application of photonics technology for PNT user equipment

The demand for seamless positioning of IoT devices both outdoors and indoors is an important requirement for many logistic applications relevant to the digital transformation of industry. This is becoming more relevant as the degree of automation in industrial operations increases, together with the need of permanently tracking the location of inputs from suppliers, to be able to forecast potential disruptions in the supply chain.

IoT seamless tracking raises fundamental issues:

- low power consumption of the receivers: PNT sensors used in IoT devices must able to work over long periods of time (in some cases over five years) with minimal battery;
- time to first fix (TTFF): in some applications, IoT devices have to be able to turn on and calculate a position fix as soon as possible, then reporting (or storing) position and turn off again. TTFF is critical for power consumption and battery durability.
- hybridization of PNT sensors, to ensure seamless outdoors and indoor interoperability.

Previous works have concluded that the main drivers to GNSS power consumption are the baseband processing (signal correlation, in particular at low signal to noise ratio level and in acquisition), the RFFE front-end functions (RF, ADC) and, idle mode (leak current and energy required to maintain the receiver in a state compatible with short TTFF and efficient acquisition upon wake-up). Efficient signal acquisition are also instrumental to the TTFF, in particular at low signal to noise ratio and/or for complex signals and waveforms.

Photonic technology offers the possibility of implementing RF signal processors with lower power consumption and broader bandwidths than traditional electronic RF signal processors. Photonic correlators are used nowadays in passive, synthetic aperture millimeter-wave (MMW) imaging, radars or electronic warfare systems. Exploring the potential of photonic technology for the implementation of hybrid PNT sensors potentially combining GNSS and other signals suitable for indoor positioning seems an interesting avenue to develop low power, low TTFF receivers for applications in IoT for industrial systems. In addition, the technology could spin into PNT to support more advanced acquisition engines, reducing power consumption.

The objective of the activity is to investigate and proof the concept of lowering the power consumption of PNT engines, for instance in IoT devices, or enhancing the processing capabilities without increasing power consumption, by using photonics technologies and processors.

The tasks to be performed include:

- assessment of which components of the traditional GNSS receivers (e.g. RF front end, AD converter, baseband correlator) could be suitably implemented and improved using photonic technology;
- analysis of RF signal processing combination with different localization systems (e.g. GNSS and WiFi) within the same photonic processors;
- implementation of a proof of concept, including breadboarding photonic circuits functions, testing performance and assessing achievable power saving;

The main results of the activity will provide:

- identification of opportunities offered by photonics processors and technologies in future PNT user equipment;
- breadboards of the photonics-based processors, associated PNT user equipment and testing environments;
- results of test campaigns for different use cases.

Funding required: €600k	*Duration:* 18 months	*ITT issue:* Q4 2021

4.3. Category 4: New Technology / New Market

4.3.1. NAVISP-El1-060: Novel privacy preserving PNT processing techniques

Up to now, cloud-based processing of positioning data (e.g. samples, raw measurements, anonymised Position, Velocity and Time) has always been susceptible to data breaches and raised concerns about privacy protection. Location-based services can fail in their path to wide-spread adoption, because they are perceived as invasive by the users and fail to properly address their risks. Similar issues appear for patient monitoring, and very recently, the COVID-19 pandemic revealed the necessity of “contact tracing” without breaking confidentiality barriers of the user. The lack of technologies allowing the processing of PNT data without impairing the user privacy has led most of the countries to avoid using PNT in “tracking apps”.

By shifting the privacy control on the user side and also decentralise processing with the involvement of the user, trusted services can be built without having to rely on the security of the infrastructure. One can bear the full responsibility for its data if, for example, if allowed to act in anonymity or to encrypt its information before it is shared for processing. Different techniques can be envisioned to avoid disclosing sensitive data. For example, homomorphic encryption allows the manipulation and processing of encrypted data sets without the need of revealing any of the original data. This enables third parties such as cloud service providers to apply various functions over the user's data while not infringing upon any privacy barriers. The user maintains all its information and encryption keys private, and computationally intensive operations are blindly performed by dedicated servers.

In the context of tracking applications, these encryption schemes can be applied over sensitive PNT data. One can process trajectory data and derive relevant events, such as intersections, and still maintain confidentiality. Moreover, to prevent security breaches, multi resolution sharing allows the user to control the granularity of information shared to different users. Other crypto technologies such as blockchain can enable a community data sharing protocol robust against tampering from malevolent parties. The distributed ledger can offer protection of data without the need of a central authority and can allow users to access it without revealing their identity.

Transferring the aforementioned processing techniques to the GNSS field will open the door for a new range of location-based-services (e.g. non-disclosing trajectory operations) and will enable highly-secure distributed GNSS architectures (e.g. cloud correlators) which will minimize the information leakage. Furthermore, applications such as healthcare analysis (e.g. disease tracking, identification of risk factors, etc) or marketing services could experience a leap by including PNT information to the plethora of big data.

Many applications could be considered, such as:

- healthcare, e.g. contact tracing for establishing risk of infection and minimizing the spread;
- incident awareness for users in areas affected by natural disasters or in an emergency state;
- automatic tolling for passenger cars;
- enforcing regulations on the airspace used by autonomous drones;
- distributed secure processing of GNSS signals.

The main objective of the activity is therefore to define and develop a proof-of-concept of an end-to-end privacy-preserving positioning solution.

The tasks to be performed include:

- investigating novel architectures, algorithms and techniques for processing GNSS data (signal, measurements, etc.) based on advanced encryption schemes and data-sharing protocols, including e.g. homomorphic cryptography, blockchain;
- developing a proof-of-concept and validating it through simulations and laboratory tests.

The main results of the activity will provide:

- breadboard demonstrator of the innovative privacy preserving concepts;
- test data, including simulation and laboratory test results and benchmark with standard PNT processing solutions in various environments;
- roadmap towards development of industrial products, for instance through initiatives in NAVISP Element 2.

Funding required: €450k	*Duration:* 15 months	*ITT issue:* Q3 2021

4.3.2. NAVISP-El1-061: Navigation payload demonstrator of future LCNS satellites

Moon exploration is emerging as the next global strategic priority in space exploration. Several dozens of commercial and institutional missions to the Moon are planned for the coming decades, with a major contribution also expected from ESA (e.g. Orion service module, ESA participation in Gateway lunar station and contribution to multiple lunar robotic missions). In spite of the wide variety of missions planned for the Moon, a lunar navigation (and communication) infrastructure is not yet available.

In light of this, and in close coordination with the HRE Directorate, the Executive has defined a reference Roadmap for Lunar PNT service provision (ref. ESA/PB-NAV(2020)9), consisting of three phases:

- Phase 1: based on the use of the signals from existing Earth GNSS constellations received thanks to high-sensitive receivers and directional antennas;
- Phase 2: complementing the use of the Earth GNSS signals with dedicated lunar orbiting ranging satellites, integrated as part of an ESA proposed Lunar Communication and Navigation Service (LCNS); and
- Phase 3: further enhancing the LCNS system with additional lunar orbiting and surface infrastructure, providing a full Lunar PNT autonomous service and full moon navigation surface coverage.

This vision is also shared with NASA, closely cooperating with ESA in this field.

In line with this roadmap and preliminary system studies being carried out in NAVISP-El1-023, a Lunar Communications and Navigation Services (LCNS) Phase

A/B1 system study has then been agreed to be launched as a joint initiative by the Telecommunications and Integrated Applications (TIA), Human and Robotic Exploration (HRE), and the Navigation (NAV) Directorates. The NAV Directorate is in charge of supporting all the PNT related aspects of this study.

In complement to the LCNS Phase A/B1 study, as explained in ESA/PB-NAV(2020)9, there is technical consensus on the importance to implement a pre-development of the most critical associated navigation technologies.

In complement to the LCNS Phase A/B1 system study, this proposed activity will assess in detail the critical technologies associated with the Navigation Payloads on-board the future lunar orbiting satellites, whose main function is to provide additional navigation signals from moon orbit to future lunar users (e.g. moon orbit, moon landing/ascent and moon surface operations).

The activity aims at developing an Elegant BreadBoard, including all functionalities of the future flight payload models identified as critical. This EBB should provide a good indication/reference of the achievable performance for this payload and of the associated mass/power/thermal/size/environmental and interface requirements, as well as confirming the compliance against the LCNS system concept and system performance allocated to the navigation payload. This activity will also define the specifications for the navigation antenna. These are of high interest in order to support the planned LCNS System studies and as a risk mitigation for the implementation of the future lunar orbiting satellites.

The objective of the activity is to:

- develop of an Elegant Breadboard (EBB) of a generic Navigation payload demonstrator for future Lunar Communication & Navigation System (LCNS) orbiting satellites;
- understand in detail the critical functionalities of future navigation payloads on-board LCNS satellites, defining associated interface requirements;
- assess achievable performance with a representative EBB unit;
- reduce the implementation risk of the future models (EM/EQM/FM) payload equipment by assessing the associated critical technologies in due-time.

The tasks to be performed include:

- review of LCNS system functional and operational concept and preliminary identification of the functional and implementation constraints for lunar navigation payloads;
- detailed identification of lunar navigation payload functionalities within LCNS satellites and preliminary assessment of the critical technologies needed;
- derivation of the Lunar NAV Payload requirements (incl external interfaces).
- design, implementation, testing and validation of the Lunar NAV Payload EBB;

- definition of the Design, Development and Validation Plan (DDVP) leading up to Lunar NAV Payload Flight model and associated recommendations applicable to the LCNS System study.

The main results of the activity will provide:

- a verified and tested representative EBB including Navigation payload critical technologies for future Lunar Communication & Navigation System orbiting satellites;
- a DDVP for the future NAV Payload Flight model;
- associated lessons learned and recommendations for the benefit LCNS System study.

Funding required: €1000k	*Duration:* 12 months	*ITT issue:* Q3 2021

4.3.3. NAVISP-El1-062: Lunar surface PNT Beacon demonstrator

In line with Phase 3 of the reference Roadmap for Lunar PNT service provision (ESA/PB-NAV(2020)9) and in complement to the development of a LCNS navigation payload Elegant Breadboard proposed above as activity NAVISP-El1-061**,** there is technical consensus on the importance to implement pre-developments of the most critical associated PNT technologies.

A PNT beacon transmitter/reference station could complement future Lunar Communication and Navigation satellites, providing additional ranging sources (from the Moon surface) and supporting their accurate orbit determination as well as potential to provide localised relative positioning and support to selenodetic/scientific applications.

This Moon PNT beacon element may in turn become an essential subsystem of the future LCNS system, providing a major support to future lunar PNT users (e.g. moon landing/ascent and moon surface operations).

The objectives of the activity are to:

- develop an Elegant Breadboard (EBB) including all functionalities of the PNT Moon beacon equipment identified as critical;
- provide a good understanding of the critical functionalities associated to this development (e.g. energy sources/autonomy, antenna technologies and associated surveying techniques, signal generation chain and transmission power needs, reception capabilities and functionalities);
- assess associated mass/power/thermal/size/environmental and interface requirements;
- confirm the expected functional/performance contributions of the Lunar PNT Beacon subsystem within the planned LCNS System. .

The tasks to be performed include:

- review of LCNS system functional and operational concept and preliminary identification of the functional and implementation constraints linked to the PNT Moon surface beacon equipment and its transportation/deployment options;
- detailed identification of PNT Moon surface beacon/reference station functionalities within LCNS System and identification and preliminary assessment of the critical technologies needed;
- derivation of the PNT Moon surface Beacon and reference station requirements;
- full implementation (in form of EBB) of the critical radio navigation functions of a PNT Moon surface beacon and reference station equipment;
- testing and validation of the EBB of the PNT Moon surface beacon equipment;
- definition of the Design, Development and Validation Plan (DDVP) leading up to PNT Moon surface beacon/reference station flight unit and associated recommendations applicable to the LCNS System study.

The main results of study will provide:

- a tested and qualified representative EBB of a generic PNT Moon surface beacon/reference station (as a critical pre-development subsystem of future LCNS);
- definition of a DDVP leading to a future PNT Moon surface beacon/reference station Flight Model;
- associated lessons learned and recommendations for the benefit of the LCNS system study.

Funding required: €800k	*Duration:* 12 months	*ITT issue:* Q4 2021

5. SUMMARY

Activity funding & duration	Funding required (€k)	Duration (months)
Category 2		
NAVISP-El1-052: Robust navigation of airborne autonomous systems with carrier phase of ARNS signals	600	18
NAVISP-El1-053: Real-time Big Data Processing for GNSS Integrity	300	12
NAVISP-El1-054: Monitoring timing signals from space. A novel approach for a worldwide robust time and synchronisation capability	450	12
NAVISP-El1-055: Attitude control of autonomous ships navigating in ports	600	18
NAVISP-El1-056: Advanced algorithms and techniques for resilient time provision	400	18
Category 3		
NAVISP-El1-057: Development of advanced VDES-R user technologies for alternative PNT	700	18
NAVISP-El1-058: Demonstration of GNSS position bounding using satellite uplinks	450	18
NAVISP-El1-059: Application of photonics technology for PNT user equipment	600	18
Category 4		
NAVISP-El1-060: Novel privacy preserving PNT processing techniques	450	15
NAVISP-El1-061: Navigation payload demonstrator of future LCNS satellites	1000	12
NAVISP-El1-062: Lunar surface PNT Beacon demonstrator	800	12
Total	6350	

El1 ID	Activity Title	2021				2022				2023			
052	Robust navigation of airborne autonomous systems with carrier phase of ARNS signals			ITT									
053	Real-time Big Data Processing for GNSS Integrity		ITT										
054	Monitoring timing signals from space. A novel approach for a worldwide robust time and synchronisation capability			ITT									
055	Attitude control of autonomous ships navigating in ports				ITT								
056	Advanced algorithms and techniques for resilient time provision		ITT										
057	Development of advanced VDES-R user technologies for alternative PNT		ITT										
058	Demonstration of GNSS position bounding using satellite uplinks			ITT									
059	Application of photonics technology for PNT user equipment				ITT								
060	Novel privacy preserving PNT processing techniques			ITT									
061	Navigation payload demonstrator of future LCNS satellites			ITT									
062	Lunar surface PNT Beacon demonstrator				ITT								