Title: ESA's LEO-PNT IoD, a small constellation showcasing the interest of a Low Earth Orbit layer as part of GNSS System of Systems

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A broad range of Positioning, Navigation and Timing (PNT) capabilities have been enabled by Global Navigation Satellite Systems (GNSS) supporting many areas in society and global economy. As reported in EUSPA EO and GNSS Market Report 2024, GNSS global revenues will rise from more than €260 billion in 2023 to around €580 billion in 2033, with shipments of GNSS receivers worldwide reaching 2 billion units per year by 2027. Despite the major impact of PNT in economy and society, jamming and spoofing events are disrupting services in different sectors on a daily basis. In this respect, complementary and alternative PNT is claimed by many user communities. In addition, digital mobility, autonomous vehicles and the future of transportation require increased availability and high-accuracy everywhere with the lowest possible waiting time (global fast-convergence of precise positioning). Consumer applications demand technology agnostic seamless solutions irrespective of their location, with increased attention towards three areas: positioning indoor in particular in large public and commercial spaces; solutions supporting positioning and navigation for personal safety in hazardous situations through the use of consumer devices; and, energy-efficient solutions that reduce the battery consumption for mobile devices, in particular for the fast-increasing Internet-of-Things devices market. The Market Report identifies how the incorporation of LEO satellites in GNSS solutions has the potential to address those needs and resolve those challenges. The European Radionavigation Plan (2023) already identifies LEO as part of promising emerging technologies and conceives that the "EU PNT ecosystem should become a System of PNT systems to achieve resilient PNT".

The majority of GNSS systems are based in Medium Earth Orbit (MEO), some of them with regional components in Geostationary Earth Orbit (GEO) or inclined/high elliptical orbits. Many applications including mass-market, professional, and even others linked to critical infrastructure heavily depend on GNSS with increased expectations for more reliable, accurate, ubiquitous services which can guarantee availability and continuity of service and resilient to vulnerabilities. A transition towards hybridisation of different systems and sensors providing a seamless experience is expected to be the trend in the future. Europe's Galileo constellation is currently the world's most accurate satellite navigation system, providing metre-level precision to users worldwide.

Global Navigation Satellite Systems (GNSS) in Medium Earth orbit (MEO), completed by augmentations systems in Geostationary orbits, such as Galileo and EGNOS are regularly upgraded to keep up with user needs. Nevertheless, these systems have intrinsic limitations, for example due to the low change of geometry that does not allow fast converge of user precise point positioning techniques. To keep improving the performance, system concepts evolutions can be envisaged, like adding additional space components layers to the system. A large constellation of satellites in Low Earth Orbits (LEO) could then be considered to supplement existing systems.

The LEO layer in the multi-layer GNSS system of systems, would allow to complement and eventually, if required, backup the main MEO GNSS layer. Ensuring a high availability quasi-global or even local coverage with a layer of satellites in LEO would require many satellites, thus an efficient and cost-effective development and deployment approach will be required. The LEO layer could thus benefit from satnav signals emitted from the MEO and GEO layers to derive its own satnav message, allowing for significant payload design simplifications. This reduced complexity also create new opportunities towards satellites mass manufacturing, "New Space" agile development approaches and simplified operation concepts, allowing to optimise the deployment schedule and cost of the LEO layer.

ESA has worked on the concept of LEO-PNT since many years, covering technology and system/mission studies. As part of the Council Ministerial 2022 the Member states approved a new programme within the Navigation Directorate called FutureNAV, which first component is LEO-PNT.

The primary objective of the FutureNAV programme Component 1 LEO-PNT is to mature and demonstrate in-orbit innovative LEO PNT space-borne, ground segment and user segment technologies and potential services, as an enabler towards LEO-PNT operational programmes to be undertaken under separate commercial and/or institutional initiatives.

The LEO-PNT IOD Component of the ESA FutureNAV Programme aims at demonstrating the potential of PNT in low Earth orbit. Its first mission will feature a small constellation of 10 demonstration satellites (large cubesats and microsats) to prototype the technology, to test the use of novel signals and frequency bands in representative environments of the end-users, showcasing the potential towards exceptional resilience, accuracy and agility in navigation that can enable a long list of new applications and services.

It is also an opportunity to foster the New Space ecosystem made of Start-ups and SMEs in Europe, to support the fast-track approach and to get concrete results rapidly from In-Orbit demonstration.

Two parallel contracts have been awarded to two independent consortiums in March 2024, one is led by GMV Aerospace and Defence S.A.U. (ES), as overall system prime and OHB System AG (DE) as space segment prime and core partner. The other contract is led by Thales Alenia Space France S.A.S (FR) as overall system prime and Thales Alenia Space SPA (IT) as space segment prime. The two consortia involve over 50 entities from 14 countries, including industrial actors with a long heritage in space, together with new actors following novel approaches to space - a combination of space primes, midcaps and SMEs, also engaging representatives from end-user communities.

Both contracts include the development and deployment of PNT payloads embarked in two types of satellites, called respectively Pathfinder A and Pathfinder B, following a test-to-learn, iterative development.

The Pathfinder A satellites are intended for early technology derisking and System Validation. Each consortium will develop, launch and operate one Pathfinder A flight model. Ground spares will also be produced and remain available to mitigate launch or early operations failures scenario. The Pathfinder A payloads will broadcast signals in L-band and S-band.

The Pathfinder B satellites will inherit the core payload design and lessons learned from the Pathfinder A satellites. It will push the in-orbit demonstration a step further towards comprehensive System Validation, Service Demonstration, early System Validation and Service Demonstration of all Payloads. Each consortium will develop and launch 4 Pathfinder B satellites. These 4 satellites will operate in synergy in nearby orbital planes to replicate the behaviour of a full constellation for defined ground user positions in a limited time window. The satellites will be spread in two LEO SSO planes separated by a RAAN shift. All satellites will be phased within their plane to optimise the Dilution Of Precision (DOP) for ground experimentations.