NAVIGATION IN THE 21ST CENTURY

LOW EARTH ORBIT POSITIONING NAVIGATION and TIMING

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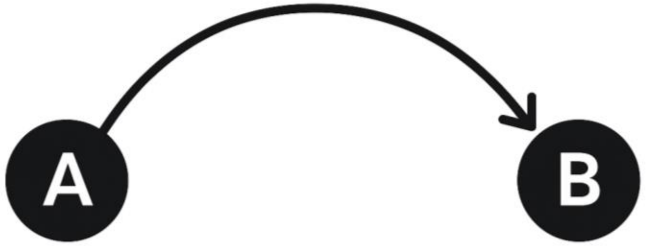
Eldar Rubinov

Presentation Outline

- Introduction
- Navigation in the 21st Century
- Rise of LEO PNT
- LEO PNT Technical Aspects
- LEO PNT Space and Receiver Segments
- LEO PNT Service Providers
- Summary

Definition of Navigation

- **ICAO** - Navigation is the process of planning, recording, and controlling the movement of a craft or vehicle from one place to another
- **IMO** - Navigation means the process of monitoring and controlling the movement of a vessel from one point to another
- **US DoD** - Navigation: The determination of the position and velocity of an object, such as a ship, aircraft, or vehicle, and the control of its movement from one place to another
- **IAIN** - Navigation is the science and technology of determining the position, velocity, and control of the motion of a vehicle or person from one place to another safely and efficiently



Getting from A to B

Different Modes of Navigation

Pedestrian

Car

Train

Plane

Ship

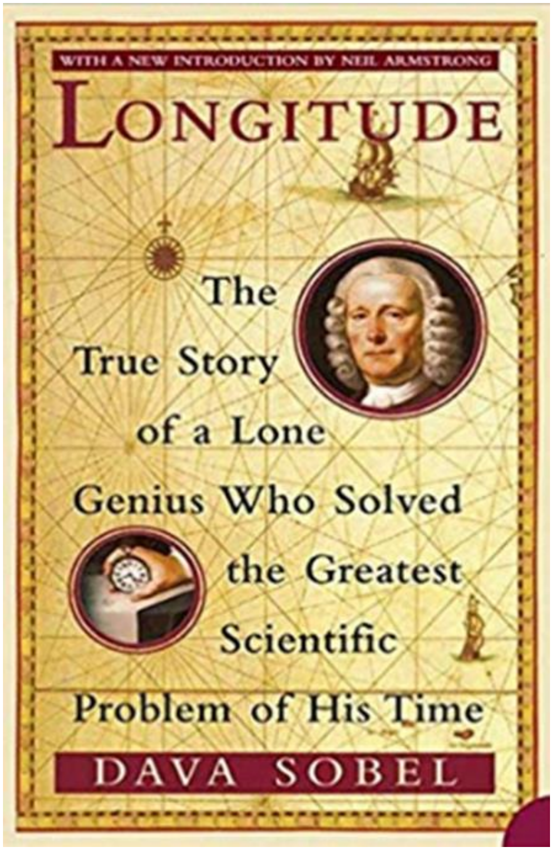
Drone

Submarine

Satellite

Navigation in the Old Days

- **Celestial navigation**
  - Sextant – measured angles between celestial bodies and the horizon to compute latitude
  - Chronometer – measured time at sea to compute longitude.
- **Dead reckoning** - estimating current position based on a previously known position, using compasses, log lines (to measure speed), and hourglasses (to track time)
- **Radio Navigation** (20th century) - before satellites, radio-based systems emerged, especially in aviation and maritime navigation:
  - LORAN (Long Range Navigation): Used low-frequency radio signals from ground stations to calculate position
  - VOR (VHF Omnidirectional Range): Widely used in aviation for en-route navigation.



The Era of Satellite Navigation (GNSS)

- GNSS has revolutionised the field of navigation forever
- The ability to achieve accurate position and time information on or near the surface of the Earth has enabled many applications that were not feasible before
- Provides global, all-weather, 24/7 positioning and timing
- Backbone of modern infrastructure - used in transport, agriculture, finance, and communications
- Relies on government-funded constellations like GPS, Galileo, GLONASS, and BeiDou
- Over 6 billion GNSS devices in use worldwide today.

Why GNSS is not enough

- As great as GNSS is, it does some drawbacks, namely:
  - It does not work well in obstructed environments, such as urban canyons
  - Single point of failure risk due to reliance on space-based signals from MEO
  - GNSS signals are extremely weak (~ -130 dBm) when reaching Earth, making them easy targets for interference
  - Increasing incidents of intentional and unintentional RF interference globally
  - GNSS alone cannot meet emerging demands for security, resilience, and integrity in critical applications.

Navigation in 21^{st} Century – More than GNSS

- In 21^{st} century GNSS alone will not be enough for many navigation applications
- Many other alternatives are currently being developed including:
  - LEO PNT
  - Terrestrial broadcast
  - Inertial Navigation Systems
  - Visual Navigation & Simultaneous Localisation and Mapping (SLAM)
  - Quantum navigation
  - Magnetic map matching
  - Celestial Navigation
  - More …

The Rise of LEO PNT

- LEO PNT is a disruptive technology advancing at a rapid pace
- Designed to augment GNSS by addressing vulnerabilities like RF interference (e.g., jamming, spoofing) and poor performance in obstructed environments
- Unlike government-operated GNSS, LEO PNT is driven by private sector innovation and market demands
- In recent years, it has attracted significant attention from both industry and research communities
- Offers stronger signals, faster positioning convergence, and potential use of diverse frequency bands beyond traditional GNSS
- Emerging as a key component in building resilient, multi-layered PNT architectures.

The Rise of LEO PNT – many initiatives are underway!

ESA kicks off two new navigation missions

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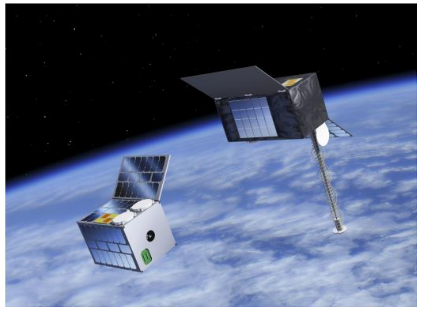
ESA / Applications / Satellite navigation

ESA has signed contracts with several European companies for an overall amount of € 233 million to develop Genesis and a LEO-PNT demonstrator, two new missions within the FutureNAV programme that will keep Europe at the forefront of satellite navigation worldwide.



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Speaking Up for GPS/GNSS Users

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Is Elon Musk Expanding Starlink to Include Satellite Positioning and Imaging Services? – Location Business News

by Editor | Oct 28, 2022 | Blog

GPS WORLD — GNSS POSITIONING NAVIGATION TIMING

GNSS OEM Autonomous Survey Mapping Transportation Defense

TrustPoint launches commercially funded PNT microsatellite

April 21, 2023 By Maddie Saines

TRUSTPOINT

On April 15, TrustPoint, an aerospace startup that provides GNSS products and services, launched its first satellite. The satellite, named It's About Time, enables TrustPoint to demonstrate core technologies as it progresses towards delivering GPS-independent global time and positioning services.

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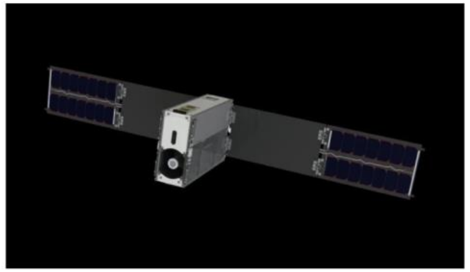
ArkEdge Space To Study LEO PNT Constellation For JAXA

Garrett Reim October 17, 2024



ArkEdge has developed a modular bus structure based on the cubesat format.

Credit: ArkEdge Space

The Japan Aerospace Exploration Agency (JAXA) has selected ArkEdge Space to study the feasibility of a low-Earth-orbit (LEO) position, navigation and timing (PNT) satellite constellation. The Tokyo-based startup will study a

Xona Space Systems raises $1m to develop world's first private GPS

May 14, 2020

Xona announced today that they closed a $1m pre-seed funding round led by 1517 with participation from Seraphim, Trucks, and Stellar Solutions.

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SKYKRAFT UNVEILS PARTNERS FOR GPS ALTERNATIVE

written by Adam Thorn | January 22, 2025

Skykraft's satellites orbiting above Australia. Illustration by Tony Bela.

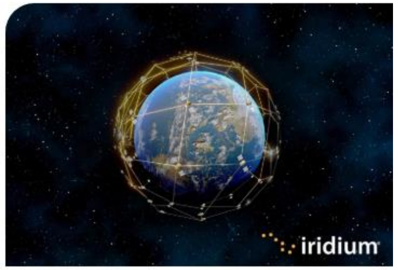
Skykraft has unveiled the list of partners it will collaborate with on its government-backed plan to create an alternative to GPS.

Iridium Satellite Time and Location Service Activated for Europe and Asia Pacific Regions

Jun 20, 2024

Increased international demand from partners to accelerate market adoption worldwide

Iridium Communications Inc., a leading provider of global voice and data satellite communications, today announced expanded commercial availability of its Satellite Time and Location (STL) service, the leading alternative positioning, navigation, and timing (PNT) solution. Driven by increased commercial demand, Iridium partners are now authorized to sell the service in parts of Europe and Asia Pacific, helping to protect locally relied upon GNSS systems, like GPS and Galileo, with a signal highly resilient to spoofing and jamming, that also helps ensure the fidelity of timing systems. Iridium STL is capable of service everywhere on the planet, and additional geographies are planned for commercial authorization as the company's partners scale and train sales and support staff.



Read the full press release on Iridium's website:

https://investor.iridium.com/2024-06-20-Iridium-Satellite-Time-and-Location-Service-Activated-for-Europe-and-Asia-Pacific-Regions

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Geely Launches 11 Satellites to Navigate Autonomous Vehicles – Location Business News

by Editor | Feb 14, 2024 | Blog

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Commercial

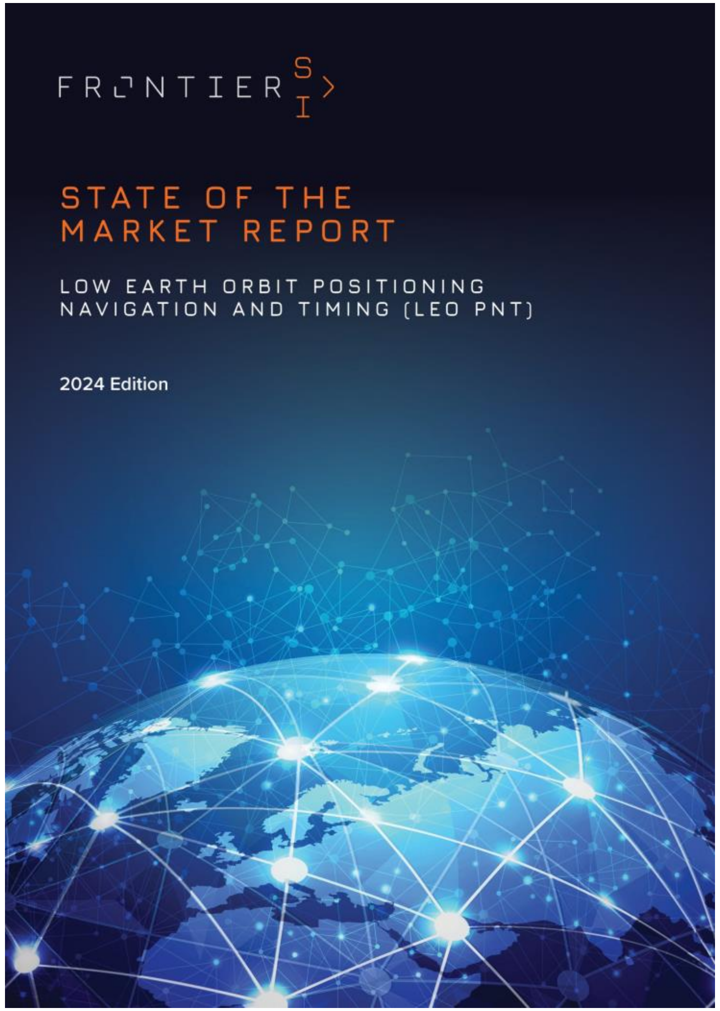
OneWeb launches alternative navigation service amid GPS vulnerability concerns

The new service is available from OneWeb Technologies, the company's U.S. proxy. OneWeb Technologies is in the process of merging with Eutelsat America Corp.

by Sandra Erwin September 10, 2024

FrontierSI LEO PNT State of the Market Report

- In January 2025 FrontierSI has received funding from the Australian Space Agency to release a LEO PNT State of the Market Report
- The report has captured the LEO PNT Market as it stands in December 2024
- Will continue to be released annually for the next few years to monitor the growth of the ecosystem



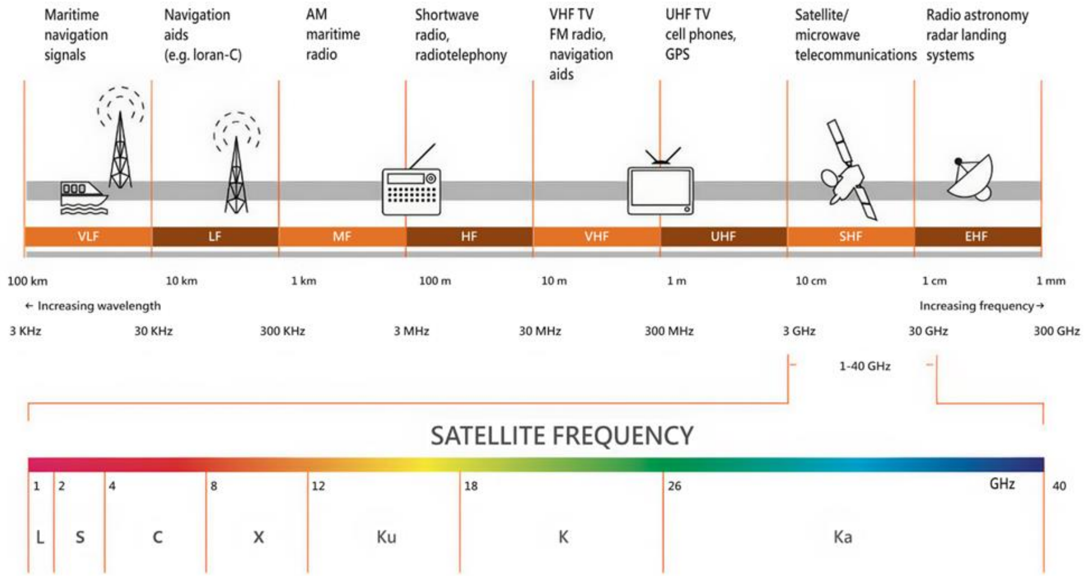
https://frontiersi.com.au/frontiersi-releases-leo-pnt-state-of-the-market-report-a-comprehensive-look-at-the-future-of-satellite-navigation/

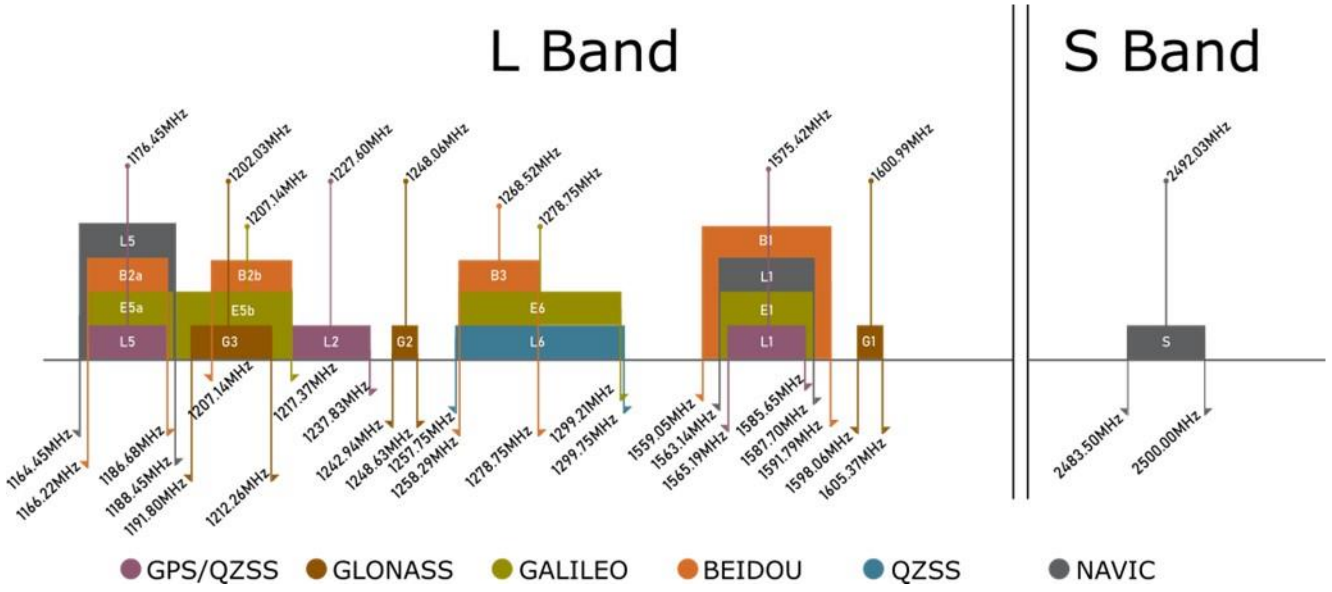
Ways to do PNT from LEO

Dedicated Constellations	Signals of Opportunity	Fused Comms & PNT systems
Dedicated satellite constellations for PNT	Opportunistic navigation	Integrated Dual Purpose Systems
Typically requires 200-500 satellites in LEO	Leverages signals from non-PNT satellites	Many new comms mega-constellations
Aimed at high accuracy applications	Mysterious signals, not designed for PNT	Thousands of satellites
Complements GNSS in a number of ways	Large ephemeris and clock errors	PNT services can be added easily
Adds an extra layer of resilience	Trials showing metre-level positioning possible	Mostly in Ku-Band
Mostly in L-band or C-band		

LEO PNT Technical Aspects – Satellite Frequencies & Signals

- Satellite frequencies and signals are essential to understand how LEO PNT differ from GNSS
- GNSS sit almost exclusively in the L-band
- C-band was considered for use in GNSS in the early 2000s, but never eventuated
- LEO PNT on the other hand exploit the full range of satellite frequencies

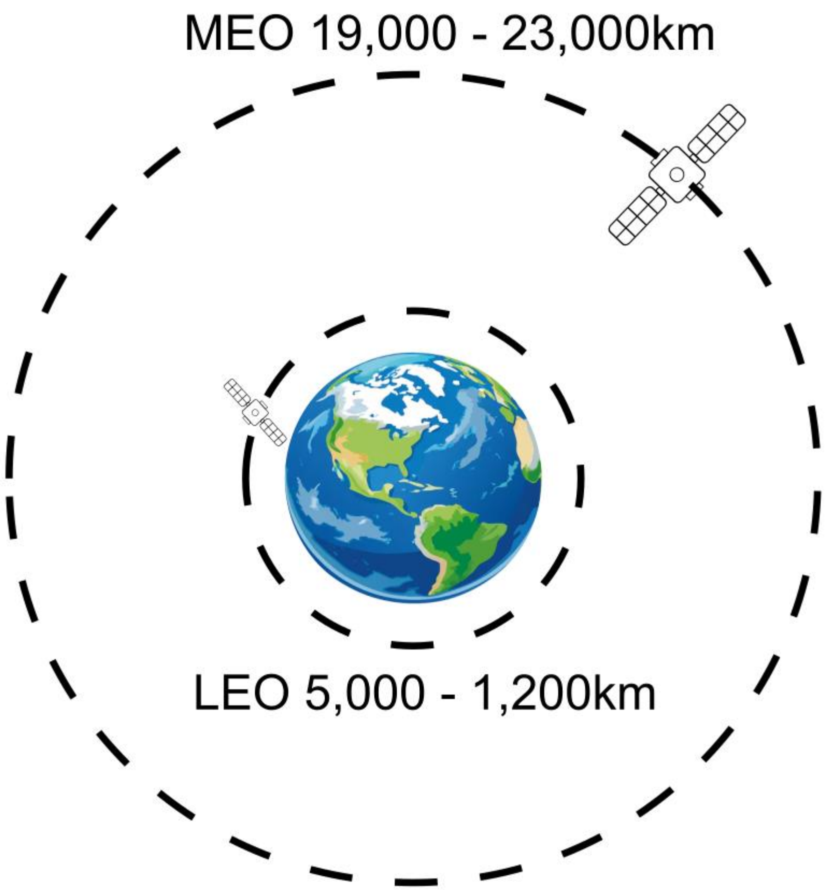




LEO PNT Technical Aspects – Precise Orbit Determination

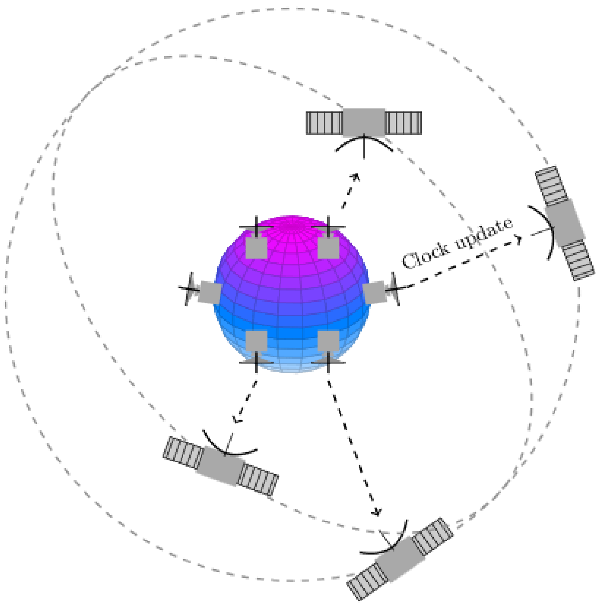
- Precise Orbit Determination (POD) is more challenging for LEO satellites compared to GNSS
- Impact of non-gravitational forces, increased orbital dynamics, rapid orbit cycles and limited tracking windows make POD more difficult

Aspect	GNSS	LEO PNT
Orbital Altitude	19,000 – 23,000km	500 – 1,200km
Orbital Period	12 hours	90 – 120 minutes
Horizon Pass	6 – 8 hours	5 – 15 minutes
POD Complexity	Stable, predictable	Highly dynamic
Forces acting on orbit	Mainly gravitational	Significant non-gravitational

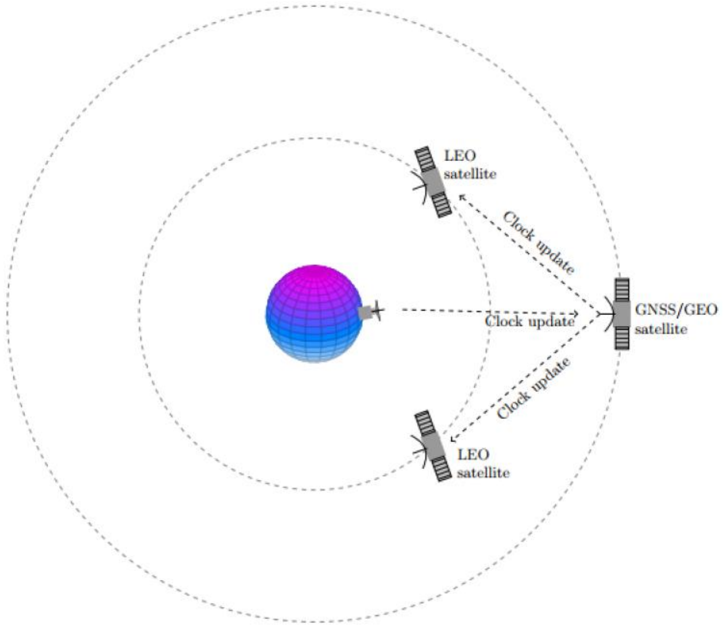


LEO PNT Technical Aspects – Timescale Reference

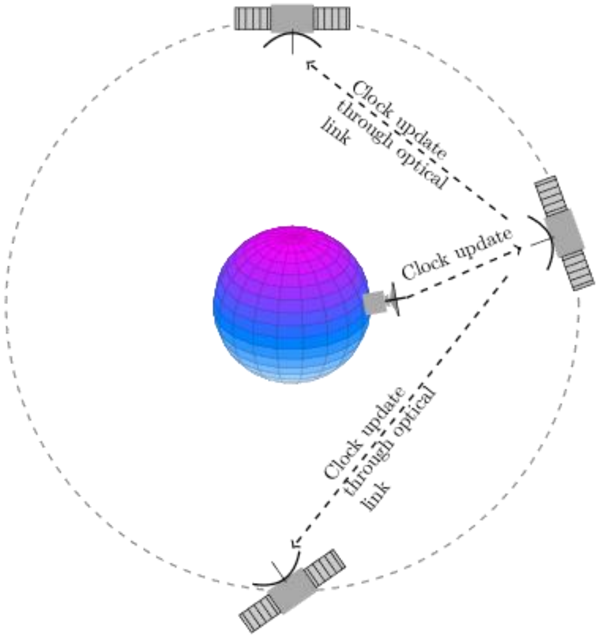
- GNSS satellites carry atomic clocks, LEO PNT satellite use smaller and cheaper Chip Scale Atomic Clocks (CSAC) or Oven-Controlled Crystal Oscillator (OCXO) clocks
- CSAC and OCXO clocks drift much faster, so need to use alternative means to synchronize the time between satellites



Ground Stations



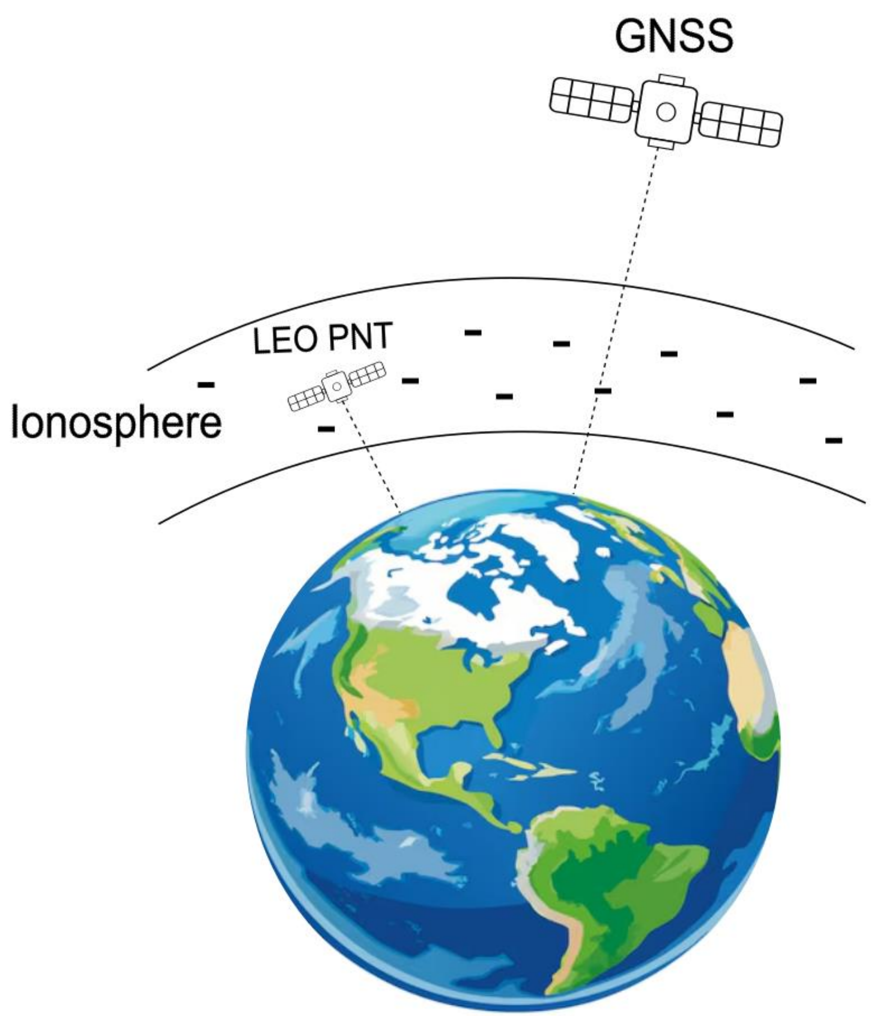
GNSS or GEO satellites



Optical Inter-Satellite Links

LEO PNT Technical Aspects – Ionospheric Effects

- Ionosphere (~70km and 1,000km) is a critical atmospheric layer for the propagation of radio navigation signals
- GNSS signals pass through ionosphere, LEO PNT satellites are inside the ionosphere
- Satellite drag and space weather effects have larger impact on LEO satellites than GNSS
- Signals from LEO satellites are more likely to be affected by space weather and other ionospheric effects (e.g., scintillation, plasma bubbles, etc.)
- More robust and resource-intensive signal processing is required to deal with the effects of the ionosphere for LEO satellites



LEO PNT Technical Aspects – Resistance to RF Interference

- LEO PNT offer several ways to combat RF interference such as jamming and spoofing:
  - **Stronger signal power** - signals transmitted from much lower altitudes, resulting in significantly higher received signal strength compared, making them harder to jam
  - **Use of Diverse Frequency Bands** - by leveraging additional bands, LEO PNT systems reduce reliance on the L-band, improving resistance to RFI
  - **Advanced Signal Design & Security Features** - emerging LEO PNT systems can incorporate robust data authenticity checks, addressing known GNSS vulnerabilities

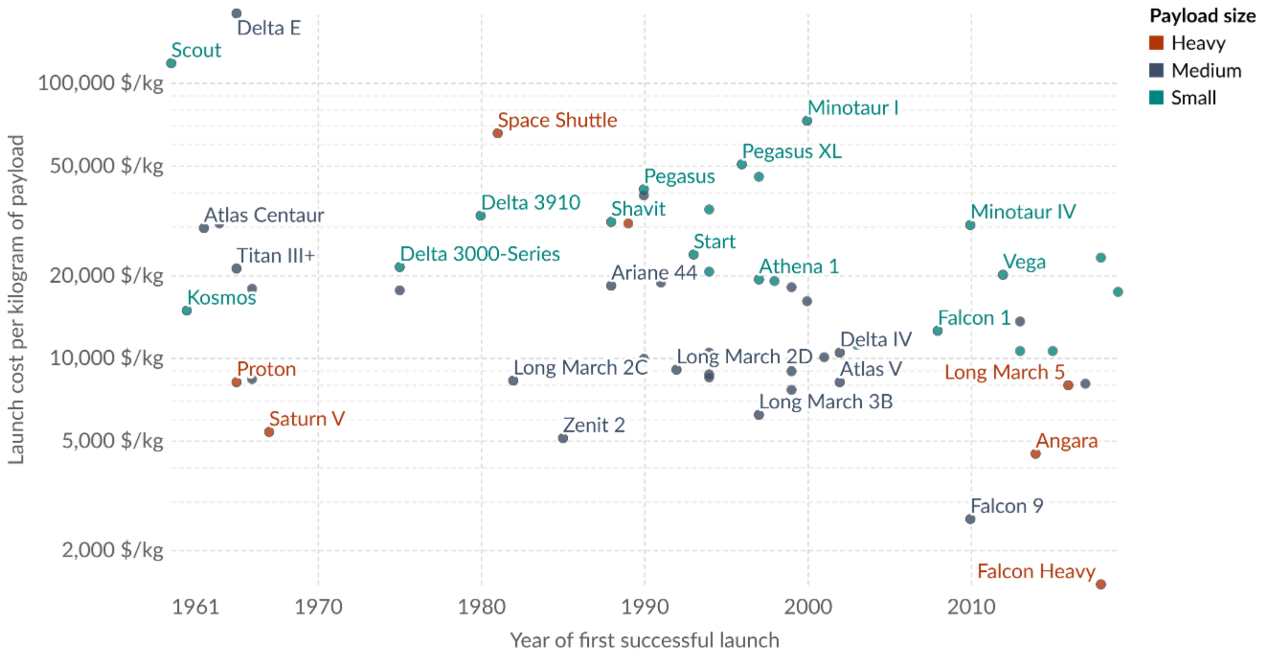
Space Segment Aspects – Launch Cost

- Launch costs historically account for one third of total space mission expenses
- From 1960s to 2010, space launch costs stagnated, limiting innovation and mission design flexibility
- SpaceX and NASA's commercial approach drastically reduced launch costs post-2010
- Cheaper launches enabled affordable deployment of large LEO constellations
- Lower launch costs directly drive the viability and rapid development of LEO PNT systems.

Cost of space launches to low Earth orbit

Our World in Data

Cost to launch one kilogram of payload mass to low Earth orbit[1] as part of a dedicated launch. This data is adjusted for inflation.



Data source: CSIS Aerospace Security Project (2022) OurWorldinData.org/space-exploration-satellites | CC BY

Note: Small vehicles carry up to 2,000 kg to low Earth orbit[1], medium ones between 2,000 and 20,000 kg, and heavy ones more than 20,000 kg.

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Space Segment Aspects – Satellite Platform

- The selection of the satellite class is a critical decision for LEO PNT systems, as it directly impacts performance, deployment costs, and operational efficiency
- For LEO PNT systems, micro and mini satellites often strike a balance between cost, capability, and scalability
- CubeSats offer low-cost options, but with limited payload capacity
- Larger satellites provide advanced capabilities, but are expensive for large-scale LEO deployments

Satellite Class	Weight (kg)	Solar Panels (kW)	Cost, M$ US
Pico	< 1	< 0.05	< 0.4
Nano	1 – 10	< 0.5	0.4 - 2
Micro	10 – 100	< 1	4 - 8
Mini	100 – 500	1 - 2	15 - 40
Small	500 – 1000	2 - 4	55 - 100
Medium	1000 – 2000	4 - 10	100 - 150
Large	> 2000	>10	> 150

Space Segment Aspects – Constellation Design

- Orbit Choices Matter: Altitude, inclination, and satellite spacing define coverage, performance, and sustainability
- Low Altitude = More Satellites Needed: Smaller coverage per satellite, faster movement, but lower latency and stronger signals.
- Inclination Strategy:
    - ➢ Polar/SSO = global coverage, but over-serves poles
    - ➢ Mid-inclination = efficient coverage for populated regions
    - ➢ Mixed inclinations balance global vs regional needs
- Plane & Satellite Spacing: More planes and satellites improve positioning accuracy through better geometry and continuous coverage.
- Trade-offs: Higher altitudes offer wider coverage, but increase radiation exposure and debris risks; lower altitudes need propulsion to counter drag.

Receiver Segment

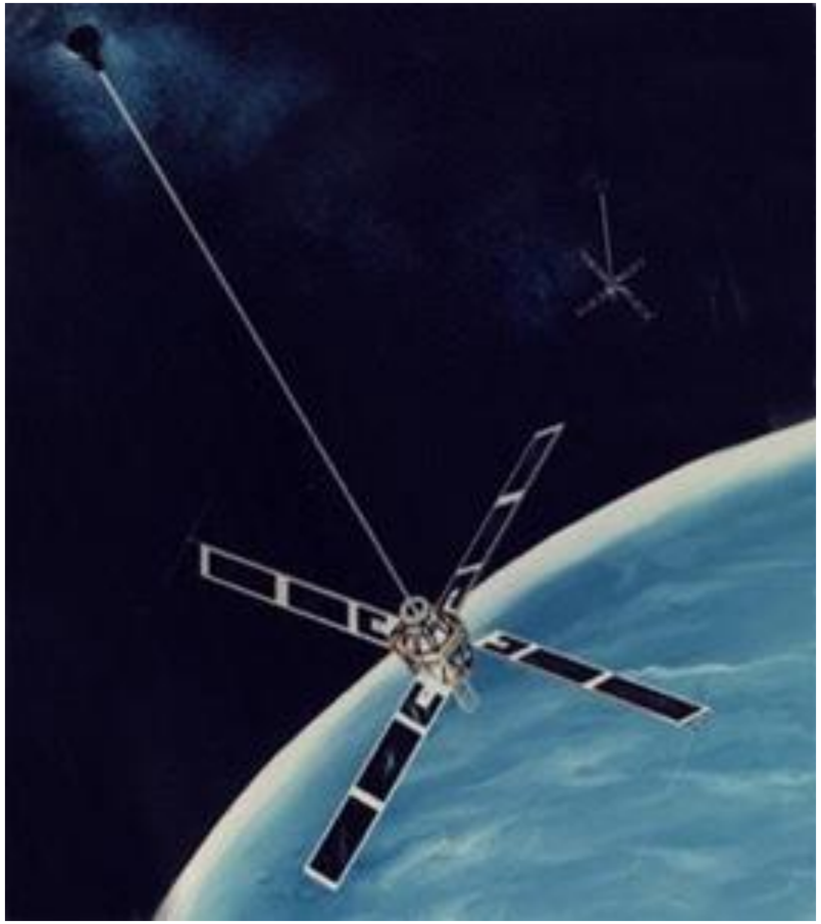
- Shift Beyond GNSS: Receiver manufacturers are integrating LEO PNT signals into their receivers
- Frequency Choices: L-band offers GNSS compatibility; C-band provides better jamming resistance, but adds design complexity
- New Business Models: Commercial LEO PNT services introduce subscription-based or bundled pricing strategies for users
- Ecosystem Growth: Collaboration with service providers, simulator companies and governments is accelerating development
- Dynamic Market: multi-constellation, adaptable receivers are emerging

LEO PNT Service Providers

Organisation	Country	First Launch	Launched	Frequency Band	Total Planned
Iridium STL	USA	2017	66	L	66
Xona Space	USA	2022	1 tech demo	L	258
TrustPoint	USA	2023	2 tech demos	C	300
JAXA	Japan	-	0	C	480
ArkEdge Space	Japan	-	0	VHF	50-100
Centispace	China	2018	5 tech demos	L	190
Geely	China	2022	0	L	240
SatNet LEO	China	2024	0	L	506
ESA's FutureNAV LEO-PNT IoD	Europe	-	0	L, S, C, UHF	10 demos (up to 263)

TRANSIT (The Original LEO PNT!)

- The first LEO PNT was the TRANSIT system, developed by DARPA and Johns Hopkins APL between 1958 and 1968.
- TRANSIT operated a constellation of 36 satellites in low Earth polar orbits (~1,075 km altitude)
- Users required 10-16 minutes to compute position by tracking a satellite's sequential passes, factoring in vessel speed and direction.
- The system transmitted on VHF frequencies (150 MHz and 400 MHz) and provided positioning accuracy between 27-37 metres, primarily supporting maritime navigation.
- TRANSIT was the world's first global satellite navigation system, widely used until it was superseded by GPS, leading to its decommissioning in 1996.



Source: https://space.skyrocket.de/doc_sdat/transit-o.htm

LEO PNT Service Providers – Iridium STL (Originally Satelles)

- Satelles launched STL in 2016 using Iridium NEXT 66-satellite LEO network (780 km, near-polar orbits)
- The only company providing commercial services now
- Number of receiver partners – Adtran, Safran, Viavi
- STL signals are ~1000x stronger than GNSS, encrypted, but pulsed, making acquisition harder
- Provides timing accuracy of 20-100 ns
- Positioning accuracy limited to 10-20 m due to low number of satellites in polar orbits
- In 2024, Satelles was acquired by Iridium, rebranding the service as Iridium® STL

General Information	
Country of Origin	USA
System Ownership	Private
Performance Targets	Timing stability 20-100 ns Positioning accuracy 10-20 m
System GNSS Independence	Independent from GNSS
Timescale Reference	Ground stations, inter-satellite links
Service Area	Global
Operational/Demonstration	Operational system
Constellation Details	
Orbital altitude	780km
Inclination	86.4° near-polar
Satellite class	Small (860kg)
Payload Type	Hosted Payload
Constellation Type	Fused Communications and PNT Constellation
No of sats in orbit Dec 2024	66 satellites
Initial Operational Capability	2017 / 40 satellites
Full Operational Capability	2019 / 66 satellites
Signal Security Architecture	
Signal structure	Proprietary
Signal Encryption	Yes
Signal Authentication	Yes
RF Characteristics	
Frequency Band	L-Band
Signal Frequency	1616-1626 MHz
User Received power	

LEO PNT Service Providers – Xona Space

- Xona Space, founded in 2019, is developing a dedicated LEO PNT constellation called PULSAR, with IOC targeted for 2026
- The PULSAR service aims for high-power, dual L-band signals (X1 and X5) with centimetre-level positioning
- Full capability will offer global, GNSS-independent PNT with encryption, authentication, and fast convergence
- Xona leads in partnerships with GNSS receiver, chipset, and simulator manufacturers at this stage
- The next satellite launch is scheduled for June 2025.

General Information	
Country of Origin	USA
System Ownership	Private
Performance Targets	2.5cm with one minute PPP convergence
System GNSS Independence	Uses GNSS in nominal operations, but can operate independently of it
Timescale Reference	GNSS and ground-based atomic timescales
Service Area	Global
Operational/Demonstration	Operational system
Constellation Details	
Orbital altitude	High LEO (exact altitude to be confirmed)
Inclination	
Satellite class	
Payload Type	Dedicated satellite
Constellation Type	Dedicated PNT Constellation
No of sats in orbit Dec 2024	0 (1 tech demo in 2022)
Initial Operational Capability	2026 / 16 satellites
Full Operational Capability	2030 / 258 satellites
Signal Security Architecture	
Signal structure	Proprietary
Signal Encryption	Signals have encryption
Signal Authentication	Signals have authentication
RF Characteristics	
Frequency Band	Dual L-band (wideband, continuous broadcast)
Signal Frequency	
User Received power	-136.2 dBW

LEO PNT Service Providers – Trustpoint

- TrustPoint, founded in 2020, is developing a commercial LEO PNT constellation using C-band signals
- Targeting decimetre-level service first, followed by centimetre-level high-accuracy positioning
- Uses ultra-compact 6U CubeSats (10 kg) with a low-cost ~$250k per satellite
- Plans a 3-phase rollout, scaling from 100 to 300 satellites for global PNT and timing services
- Focused on affordability, GPS augmentation, secure synchronisation, and scalability in LEO PNT

General Information	
Country of Origin	USA
System Ownership	Private
Performance Targets	Decimetre-Level Core Service Centimetre-Level High Precision Service
System GNSS Independence	Independent of GNSS
Timescale Reference	Time transfer from company operated ground segment
Service Area	Global
Operational/Demonstration	Operational system
Constellation Details	
Orbital altitude	< 700 km
Inclination	
Satellite class	Nano (6U, 10kg cubesat)
Payload Type	Dedicated satellite
Constellation Type	Dedicated PNT Constellation
No of sats in orbit Dec 2024	2 tech demos
Initial Operational Capability	2027 / 100+ satellites
Full Operational Capability	2029 / 300+ satellites
Signal Security Architecture	
Signal structure	Proprietary
Signal Encryption	Signals have encryption
Signal Authentication	Signals have authentication
RF Characteristics	
Frequency Band	C-band
Signal Frequency	5020 MHz Center Frequency
User Received power (dBW)	Variable, -158 to -148 dBW

LEO PNT Service Providers – JAXA

- JAXA is developing a LEO PNT constellation to augment GNSS and enable ultra-rapid PPP convergence times
- The constellation will also exploit the C-band for its navigation signals
- Phase 1 is targeting 240 satellites by 2030, enabling decimetre-level positioning with ~3-minute convergence
- Phase 2 will have 480 satellites by 2035, aiming for even faster convergence
- JAXA has contracted ArkEdge Space to study the feasibility of the LEO PNT constellation

General Information	
Country of Origin	Japan
System Ownership	Not decided
Performance Targets	Phase I: 10cm, 3 minutes Phase II: 10cm, 1 minute
System GNSS Independence	System is designed to augment GNSS
Timescale Reference	GNSS and ground stations
Service Area	Global
Operational/Demonstration	Operational system
Constellation Details	
Orbital altitude	975 km
Inclination	55°
Satellite class	
Payload Type	Dedicated Satellite
Constellation Type	Dedicated PNT Constellation
No of sats in orbit Dec 2024	0
Initial Operational Capability	2030 / 240 satellites
Full Operational Capability	2035 / 480 satellites
Signal Security Architecture	
Signal structure	
Signal Encryption	
Signal Authentication	
RF Characteristics	
Frequency Band	C-Band
Signal Frequency	5030-5250 MHz
User Received power (dBW)	

LEO PNT Service Providers – ArkEdge Space

- ArkEdge Space, founded in 2018, specialises in nanosatellites and is conducting a JAXA-backed LEO PNT feasibility study
- Additionally, ArkEdge Space is developing a maritime PNT service using VHF Data Exchange System (VDES) with positioning via VDES-R mode
- VDES offers PNT over oceans using existing ITU-supported frequencies, but lacks terrestrial coverage
- Future VDES constellation expected to have 50-100 satellites at 500-600 km altitude, with 1-3 satellites in view
- ArkEdge is also leading Japan's Lunar Navigation Satellite System (LNSS) development with NASA and ESA.

General Information	
Country of Origin	Japan
System Ownership	Private
Services Provided	VDES R-Mode
System GNSS Independence	
Timescale Reference	
Service Area	60°N to 60°S, over ocean surface only
Operational/Demonstration	Operational system
Constellation Details	
Orbital altitude	500-600 km
Inclination	Sun-Synchronous or Mid-Inclination
Satellite class	Micro
Payload Type	Dedicated Satellite
Constellation Type	Fused Communications and PNT Constellation
No of sats in orbit Dec 2024	0
Initial Operational Capability	
Full Operational Capability	
Signal Security Architecture	
Signal structure	
Signal Encryption	
Signal Authentication	
RF Characteristics	
Frequency Band	VHF
Signal Frequency	157-162 MHz
User Received power (dBW)	

LEO PNT Service Providers – Centispace

- Centispace is a Chinese commercial LEO PNT constellation developed by Beijing Future Navigation and CETC-29
- Designed to broadcast L-band signals compatible with existing GNSS receivers, supporting BeiDou by reducing PPP convergence times
- Planned constellation includes 190 satellites across three orbital segments for global coverage
- Demonstration satellites are already in orbit for performance trials.

General Information	
Country of Origin	China
System Ownership	Private
Performance Targets	High Accuracy Service: < 10cm Integrity Service: Availability 99.99%, Alarm time: < 3s
System GNSS Independence	System is designed to augment GNSS
Timescale Reference	GNSS and ground stations
Service Area	Global
Operational/Demonstration	Operational
Constellation Details	
Orbital altitude	Segment 1 – 975 km; Segment 2 & 3 – 1100 km
Inclination	Segment 1 - 55°; Segment 2 – 87.4°; Segment 3 - 30°
Satellite class	Mini (100kg)
Payload Type	Dedicated satellite
Constellation Type	Dedicated PNT Constellation
No of sats in orbit Dec 2024	5 tech demos
Initial Operational Capability	
Full Operational Capability	2026 / 190
Signal Security Architecture	
Signal structure	
Signal Encryption	
Signal Authentication	
RF Characteristics	
Frequency Band	L-Band
Signal Frequency	CL1 – 1569-1581 MHz CL5 – 1170-1182 MHz
User Received power (dBW)	-157.0

LEO PNT Service Providers – Geely

- Geely Holding is a Chinese multinational automotive manufacturer which owns brands such as Volvo, Zeekr, Polestar, Proton, Smart and Lotus
- Geely established GeeSpace in 2018 to develop the GEESATCOM communications and PNT constellation
- The full GEESATCOM plan includes 5,676 LEO satellites for broadband communications
- A subset of 240 satellites is expected to provide PNT services
- Limited public information is available on the PNT constellation's design and capabilities

General Information	
Country of Origin	China
System Ownership	Private
Performance Targets	
System GNSS Independence	
Timescale Reference	
Service Area	Global
Operational/Demonstration	Operational system
Constellation Details	
Orbital altitude	620km
Inclination	
Satellite class	Mini (100 kg)
Payload Type	
Constellation Type	Fused Communications and PNT Constellation
No of sats in orbit Dec 2024	
Initial Operational Capability	
Full Operational Capability	240
Signal Security Architecture	
Signal structure	
Signal Encryption	
Signal Authentication	
RF Characteristics	
Frequency Band	L-Band
Signal Frequency	
User Received power (dBW)	

LEO PNT Service Providers – Satnet LEO

- China SatNet is developing a LEO PNT system called SatNet LEO alongside the Guowang mega constellation
- Limited public information is available on the constellation's design and capabilities
- ICG 2024 workshop summary indicates a planned constellation of 508 satellites by 2030.
- Other details remain undisclosed at this stage

General Information	
Country of Origin	China
System Ownership	
Performance Targets	
System GNSS Independence	
Timescale Reference	
Service Area	Global
Operational/Demonstration	Operational
Constellation Details	
Orbital altitude	
Satellite class	
Payload Type	
Constellation Type	
No of sats in orbit Dec 2024	
Initial Operational Capability	2025 / 168
Full Operational Capability	2030 / 508
Signal Security Architecture	
Signal structure	
Signal Encryption	
Signal Authentication	
RF Characteristics	
Frequency Band	
Signal Frequency	
User Received power (dBW)	

LEO PNT Service Providers – ESA's FutureNAV LEO-PNT IoD

- ESA envisions a multi-layered "system of systems" PNT architecture, with LEO satellites providing space-based diversity
- Currently running the LEO-PNT IoD mission under the FutureNAV program to accelerate LEO PNT development
- Two contracts awarded to GMV (Spain) and Thales Alenia Space (France) for in-orbit demonstrators
- Each consortium will launch 5 satellites (Pathfinder A & B types) starting in 2025, with trials planned for 2026-2027
- Public details remain limited, with missions focused on testing multi-frequency PNT services.

General Information		
Country of Origin	Europe	
System Ownership	Institutional or Commercial	
Performance Targets	Decimetre-level positioning; nanosecond-level timing accuracy	
System GNSS Independence	Augmentation to GNSS	
Timescale Reference	GNSS	
Service Area	Regional Demonstrator building up to global operational service	
Operational/Demonstration	Demonstration	
Constellation Details	**GMV**	**TAS**
Orbital altitude	550 km	550 km
Inclination	Quasi Polar Orbit	Quasi Polar Orbit
Satellite class	12U CubeSat (Pathfinder A) 4 x 100kg Microsats (Pathfinder B)	16U CubeSat (Pathfinder A) 4 x 30kg Microsats (Pathfinder B)
No of sats in orbit Dec 2024	First satellite planned in 2025	First satellite planned in 2025
Initial Operational Capability		
Full Operational Capability	2027 / 5 satellites	2027 / 5 satellites
Signal Security Architecture	**GMV**	**TAS**
Signal structure		
Signal Encryption		
Signal Authentication		
RF Characteristics	**GMV**	**TAS**
Frequency Band	L/S, C and UHF Signal in Space and 2-way payload (S-band)	L/S, C and UHF Signal in Space and 2-way payload (UHF-band)
Signal Frequency (MHz)		
User Received power (dBW)		

LEO PNT Market Penetration

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GNSS POSITIONING NAVIGATION TIMING

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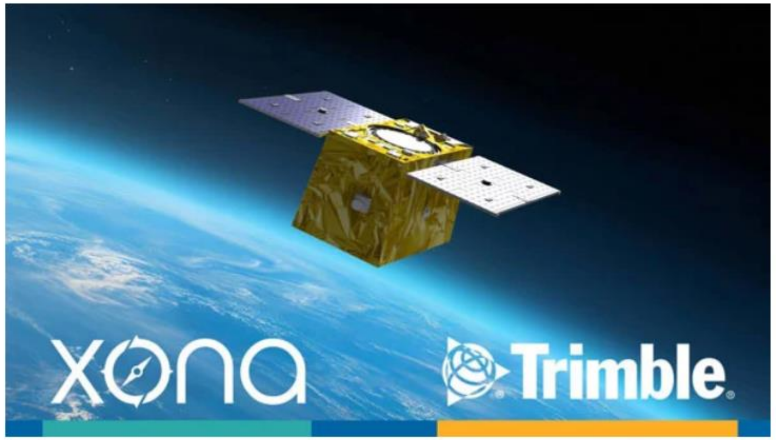

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April 23, 2025

By Inside GNSS

HEXAGON

Emerging SatCom Constellations – will they also do PNT?

Company	Constellation	Country	First Launch	Launched	Frequency	Total Planned
SpaceX	Starlink	USA	2019	7000+	Ku, Ka	42,000
China SatNet	Guowang	China	2024	10	Ku, Ka	12,992
SSST	G60	China	2024	36	Ku	12,000
Hongqing Technology	Honghu-3	China	-	0		10,000
GeeSpace	GEESATCOM	China	2022	30		5,676
Lynk	Lynk	USA	2022	6	L	5,000
Amazon	Kuiper	USA	2023	2	Ku, Ka	3,236
Skykraft	Skykraft	Australia	2023	10	S	2,976
EutelSat OneWeb	OneWeb Gen I	France, UK	2019	634	Ku, Ka	648
Rivada	OuterNET	USA	-	0	Ka	576
CASC	Hongyan-1	China	2018	1	Ka, L	320
SpaceRise	$IRIS^2$	EU	-	0	Ka, S	290
Sateliot	Sateliot	Spain	2023	6	L	250
Telesat	Lightspeed	Canada	-	0	Ku, Ka	198
AST SpaceMobile	Bluebird	USA	2023	5	L, S	168
ArkEdge	ArkEdge	Japan	-	0	VHF	50-100
Iridium	NEXT	USA	2017	80	L	80
Globalstar	Globalstar	USA	1998	48	S	65
Orbcomm	Orbcomm	USA	1995	31	L, S	31

Summary

- GNSS transformed navigation, but faces growing challenges in the 21st century
- LEO PNT is emerging as a critical complement, enhancing resilience, accuracy, and security
- Multiple global initiatives, both commercial and institutional, are driving rapid LEO PNT development
- Receiver technology and business models are evolving to integrate multi-constellation PNT solutions
- The future of navigation lies in diverse, multi-layered PNT architectures where GNSS, LEO PNT, terrestrial systems, and alternative methods work together

Questions

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