GPS/GNSSシンポジウム2022

高精度測位補強サービスの現状と将来

Status and Future of Correction Services for GNSS Precise Positioning

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2022-10-19 ~ 2022-10-21 @Online (Virtual)

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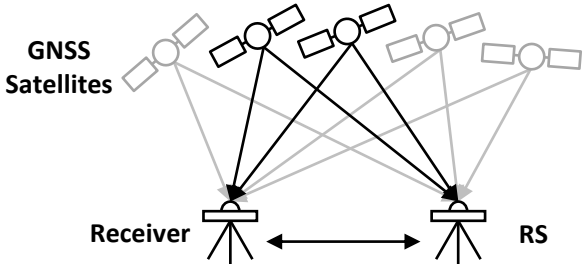
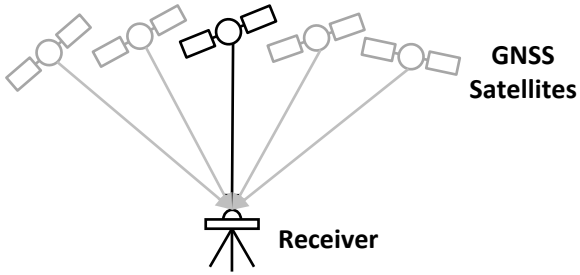
- Correction Services for PPP/PPP-RTK
- Open Services by GNSS
- Commercial Services
- LEO PNT
- Future of Correction Services

Correction Services for PPP/PPP-RTK

Precise Positioning with GNSS





Type		RTK		PPP-RTK	PPP	
		RTK	NRTK		PPP-AR	PPP
Practical Product/ Service		1992 ~ (Trimble 4000)	1998 ~ (SAPOS)	2015 ~ (Trimble RTX Fast)	2011 ~ (Trimble RTX)	1998 ~ (NavCom StarFire)
Correction Data		OSR (RS OBS)	OSR (VRS, FKP, MAC)	SSR (Orbit, Clock, STEC, ZTD, Code Bias, Phase Bias)	Orbit, Clock, Code Bias, Phase Bias, (VTEC)	Orbit, Clock, Code Bias
Typical Specs	Coverage	Local (Baseline Length < 30 km)	Regional		Global	
	Accuracy (H-RMS)	1 cm + 1 ppm	~ 2 cm	2 ~ 6 cm	2 ~ 15 cm	5 ~ 20 cm
	Convergence Time	< 30 s	< 30 s	< 60 s	3 ~ 15 min	10 ~ 30 min

PPP/PPP-RTK Applications

Broad Applications of PPP/PPP-RTK ...

Agriculture

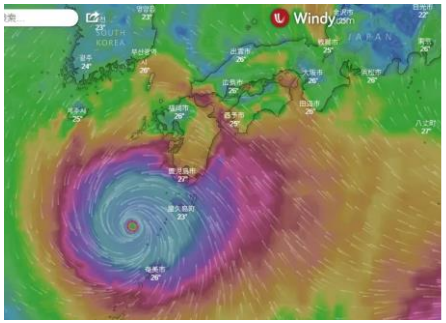
Construction/ Mining

Unmanned Vehicle

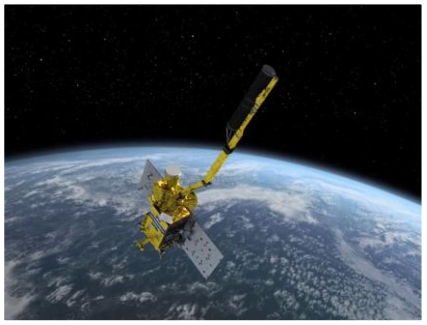
Automotive (ADAS/AD)

Natural Hazard Warning

Precise Time Synchronization

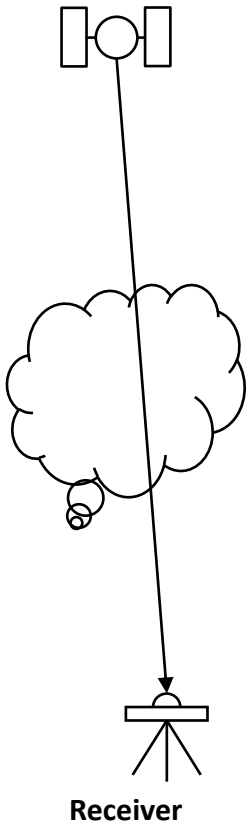


Atmosphere Observation



Spacecraft POD and Navigation

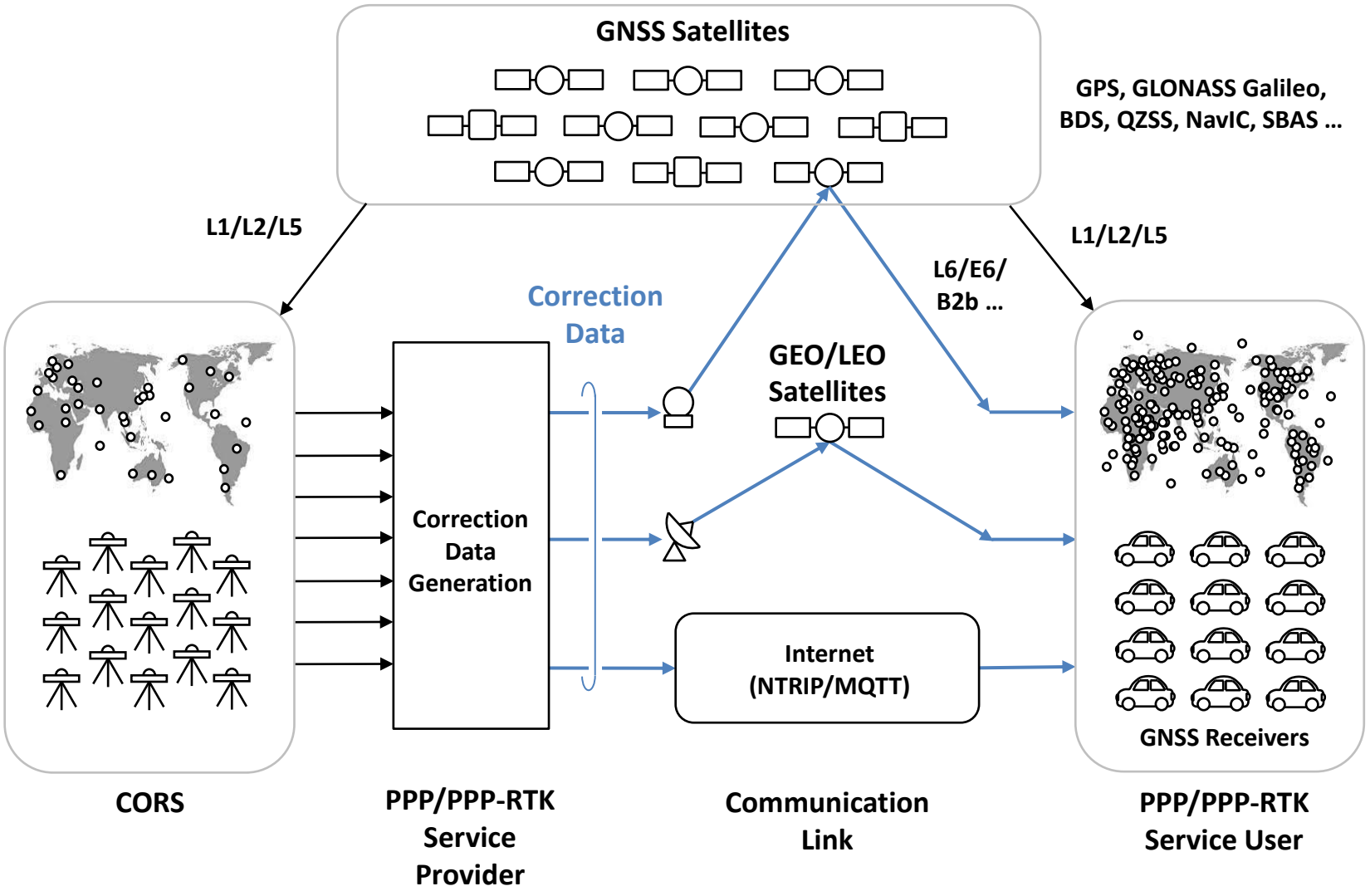
Correction Data for PPP/PPP-RTK



Error Sources		Correction Data				
		RTK/NRKT	PPP-RTK	PPP-AR	PPP	
GNSS Satellite	Orbit	RS/VRS OBS	Orbit	Orbit	Orbit	Global Corrections
	Clock Bias		Clock	Clock	Clock	
	Code Bias		Code Bias	Code Bias	Code Bias	
	Phase Bias		Phase Bias	Phase Bias	-	
Ionosphere			STEC	(VTEC)	Eliminated by Dual-Freq	Regional/ Local Corrections
Troposphere			ZTD	Estimated	Estimated	
Receiver	Multipath	-	-	-	-	User Dependent Errors
	Clock Bias	Eliminated by DD	Estimated	Estimated	Estimated	
	Code Bias					
	Phase Bias	Fixed	Fixed	Fixed	Estimated	
	Noise	-	-	-	-	

: OSR Corrections : SSR Corrections

Correction Service Architecture



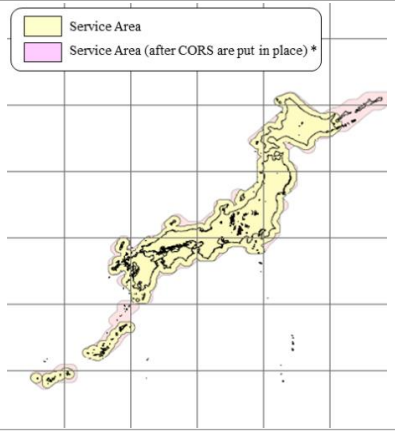
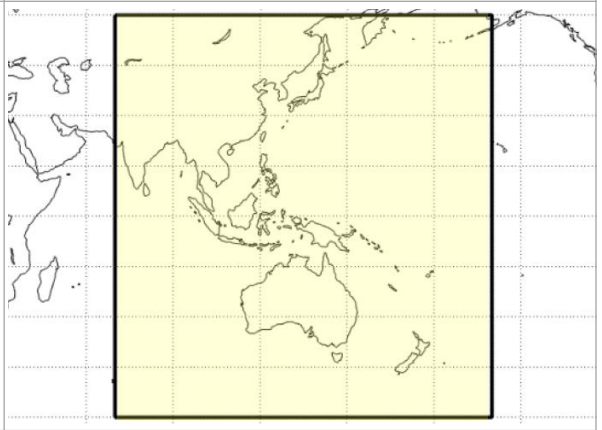
Open Services by GNSS

Open Services by GNSS

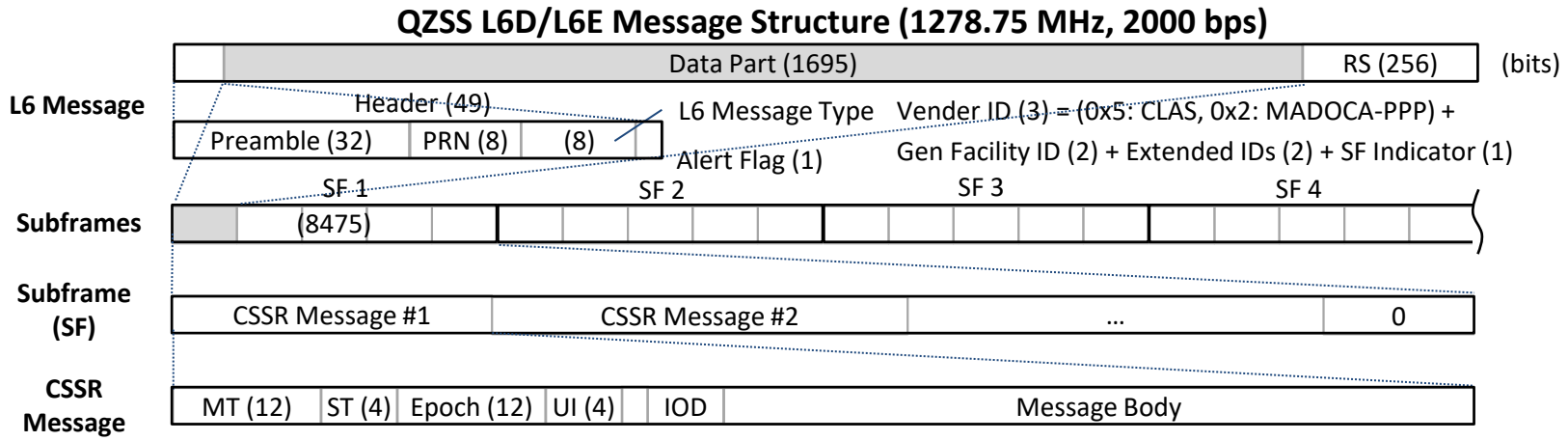
Service	QZSS		Galileo HAS *1	BDS PPP-B2b	SouthPAN OS-PVS *2	GLONASS HAS *1	KPS CLS *3
	CLAS	MADOCA-PPP					
Correction Type	PPP-RTK	PPP-AR	PPP-AR	PPP	PPP	PPP-AR	PPP ?
Communication Link	QZSS L6D	QZSS L6E	Galileo E6B	BDS-3 (GEOx3) B2b	Inmarsat 4F1 (GEO) L5	LUCH-5M (GEOx3) L3SVI	KPS L6 ?
Data Rate	1695 bps	1695 bps	448 bps	486 bps	226 bps	> 3 kbps	?
Data Format	CSSR	CSSR	Similar to CSSR	Similar to CSSR	DFMC SBAS MT32	?	?
Service Area	Japan	Asia/Oceania	Europe (Initial) Global (Full)	Asia-Pacific	Australia/ New Zealand	Russia	Regional
Target GNSS	GPS, GAL, QZS	GPS, GLO, GAL, QZS	GPS, GAL	GPS, BDS	GPS, GAL	GPS, GLO, BDS, GAL, NavIC	?
Accuracy	H 12 cm (95%) V 24 cm (95%)	H 30 cm (95%) V 50 cm (95%)	H 20 cm (95%) V 40 cm (95%)	H 20 cm (95%) V 35 cm (95%)	H 0.375 m V 0.525 m	?	?
Convergence Time	60 s (95%)	1800 s (Ph.1) 600 s (Ph.2)	300 s (Global) 100 s (Europe)	1200 s	4800 s	?	?
Status/ Plan	Operational (2018/11~)	Trial (2022/9~) Phase 1 (2024/4~) Phase 2 (2026~ ?)	Test (2020~) Initial Service (2022~) Full Service (2024~ ?)	Operational (2020/7~)	Early Service (2022/9~)	Initial Service (2025~)	Initial Service (2029~ ?)

*1 High Accuracy Service, *2 PPP via SBAS Open Service, *3 Centimeter Level Service

QZSS CLAS/MADOCA-PPP (1/2)

Service		CLAS	MADOCA-PPP	
			Phase 1	Phase 2
Corrections	Orbit / Clock	Y / Y	Y / Y	
	Code Bias / Phase Bias	Y / Y	Y / Y	
	Ionosphere / Troposphere	Y (STEC) / Y	N / N	Y (VTEC) / N
Corrected Signals	GPS	L1C/A, L1C, L2P, L2C, L5	L1C/A, L1P, L1C, L2C, L2P, L5	
	GLONASS	-	G1, G2	
	Galileo	E1b, E5a	E1, E5a	
	QZSS	L1C/A, L1C, L2C, L5	L1C/A, L1C/B, L1C, L2C, L5	
Service Area				
Accuracy		Static: H ≤ 6 cm, V ≤ 12 cm (95%) Kinematic: H ≤ 12 cm, V ≤ 24 cm (95%)	H ≤ 30 cm (95%) V ≤ 50 cm (95%)	
TTFF/Convergence Time		≤ 60 s (95%)	≤ 1800 s	≤ 600 s
Service Start		2018/11/1	2022/9/30 (Trial) 2024/4	2024/4 (Trial) 2026 ?

QZSS CLAS/MADOCA-PPP (2/2)



CSSR Messages (): Update interval (s)

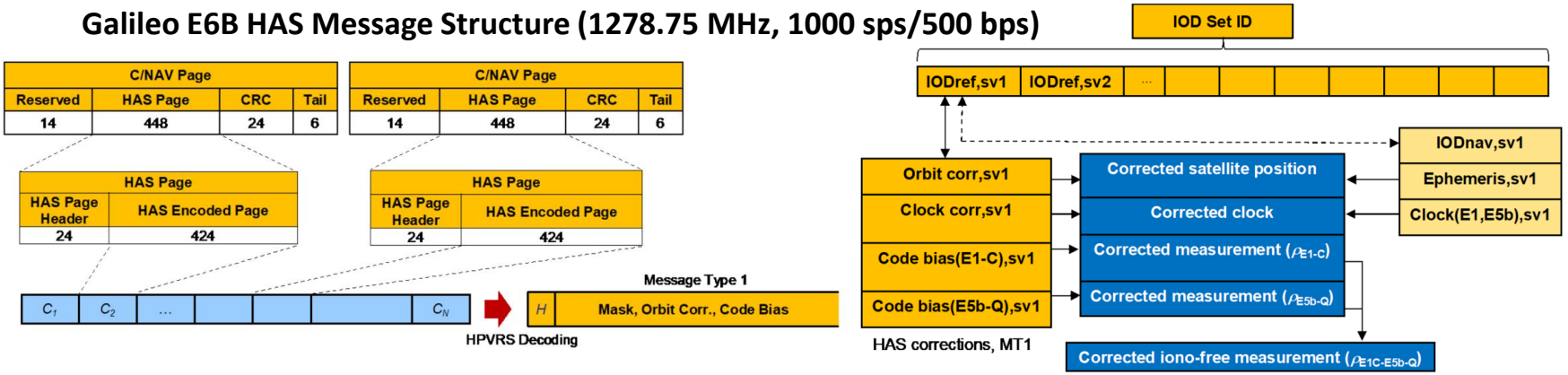
MT.ST	Name	Unit of Corrections	CLAS		MADOCA-PPP
			2018/11/1~	2020/11/30~	
	L6 Message	-	L6D (PRN193-201)		L6E (PRN204-211)
4073.1	CSSR Mask	-	Y (30)	Y (30)	Y (30)
4073.2	CSSR GNSS Orbit Correction	SV	Y (30)	Y (30)	Y (30)
4073.3	CSSR GNSS Clock Correction	SV	Y (5)	Y (5)	Y (5)
4073.4	CSSR GNSS Satellite Code Bias	SV/Signal	Y (30)	Y (30)	Y (30)
4073.5	CSSR GNSS Satellite Phase Bias	SV/Signal	Y (30)	-	Y (30)
4073.6	CSSR GNSS Code and Phase Bias	SV/Signal/Network	Y (30)	Y (30)	-
4073.7	CSSR GNSS URA	SV	Y (30)	Y (30)	Y (30)
4073.8	CSSR STEC Correction	All	Y (30)	-	-
4073.9	CSSR Gridded Correction	Network/Grid	Y (30)	-	-
4073.10	CSSR Service Information	All	-	-	-
4073.11	CSSR GNSS Combined Correction	SV/Network	Y (30)	Y (30)	-
4073.12	CSSR Atmospheric Correction	Network/Grid	-	Y (30)	-

IS-QZSS-L6-005, QZSS Interface Specification Centimeter level Augmentation Service, September, 2022
IS-QZSS-MDC-001, QZSS Interface Specification Multi-GNSS Advanced Orbit and Clock Augmentation – Precise Point Positioning, February, 2022

Galileo HAS (1/2)

Phase		Phase 0 (SIS Testing)	Phase 1 (Initial Service)	Phase 2 (Full Service)
Corrections	Orbit/Clock/ Code Bias/Phase Bias	Y / Y / Y / N	Y / Y / Y / Y	Y / Y / Y / Y
Corrected Signals	Galileo	E1, E5a, E5b, E6	E1, E5a, E5b, E5, E6	E1, E5a, E5b, E5, E6
	GPS	L1, L2P	L1, L2C	L1, L2C, L5
Coverage		EU +	EU +	Global
Accuracy	Horizontal (95%)	N/A	> 20 cm	20 cm
	Vertical (95%)	N/A	> 40 cm	40 cm
Convergence Time	Service Level 1 (Global)	N/A	> 300 s	300 s
	Service Level 2 (EU)	N/A	N/A	100 s
Ground Reference Stations		14 (GSS)	14 (GSS)	TBD
Max Sat. Downlinks (448 bps)		20	20	TBD
Authentication		N	N	Y
Phase Start		2020	2022	2024 +

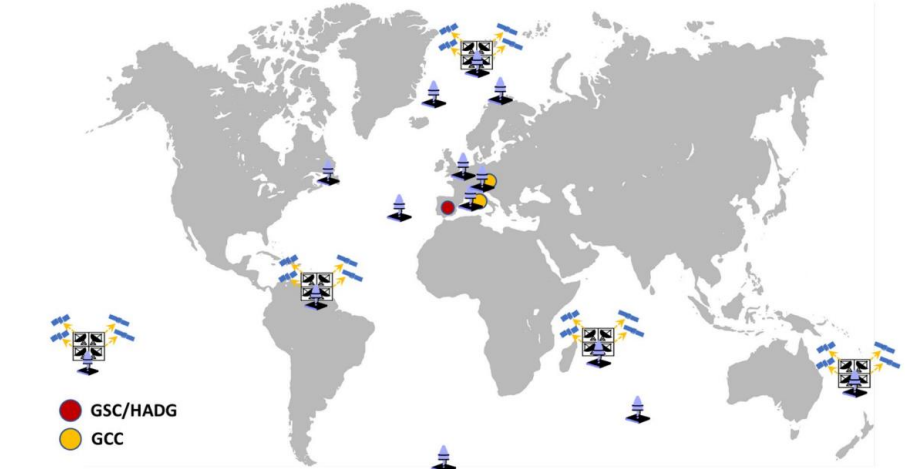
Galileo E6B HAS Message Structure (1278.75 MHz, 1000 sps/500 bps)

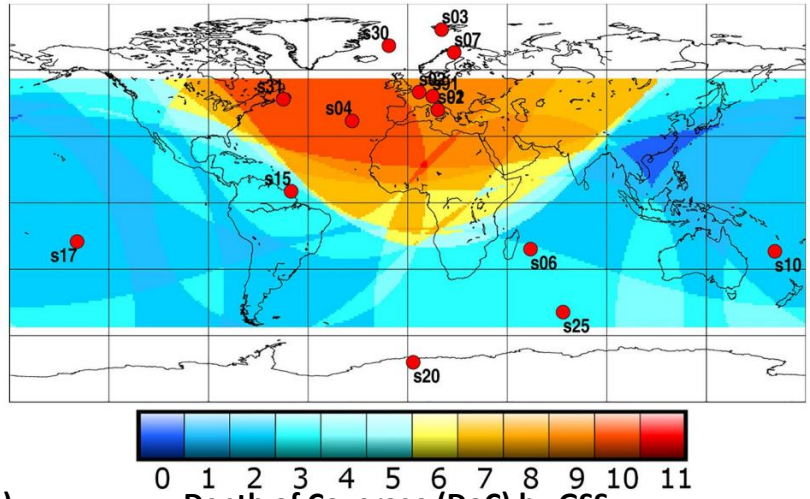


I-F-Hernandez et al., Galileo high accuracy service: initial definition and performance, GPS Solutions, 2022

Galileo HAS (2/2)

Galileo HAS Phase 1 Ground Stations

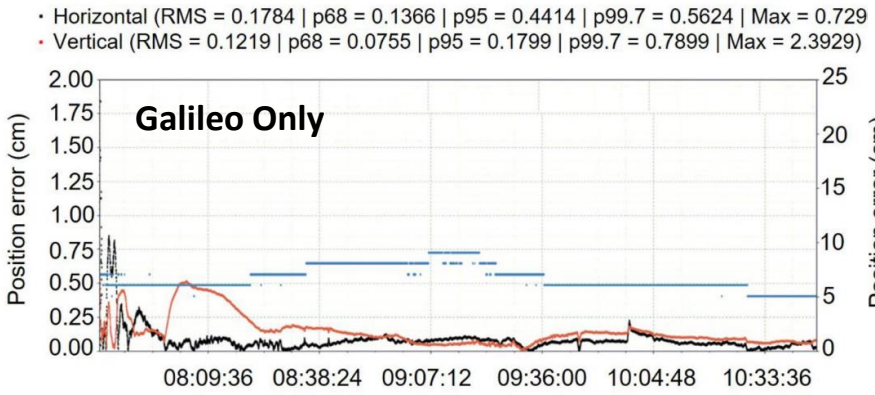


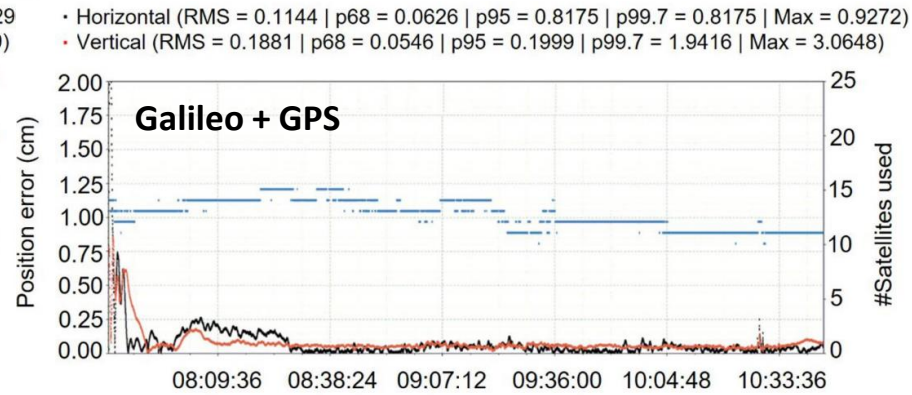


: ULS (Up-Link Station) (5) : GSS (Galileo Sensor Station) (14)

Depth of Coverage (DoC) by GSS

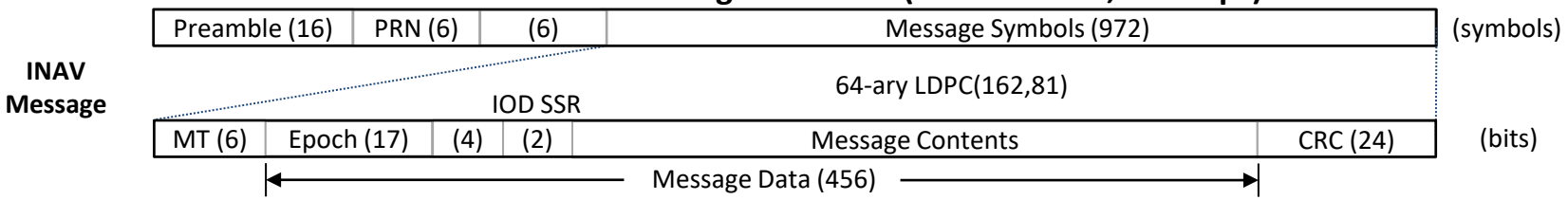
Galileo HAS PPP Results (May 25, 2021, at Spain)





BDS PPP-B2b

BDS PPP-B2b INAV Message Structure (1207.14 MHz, 1000 sps)

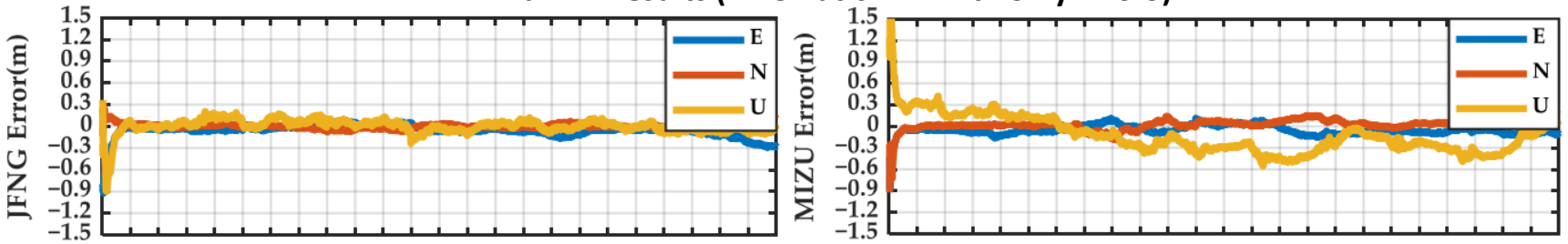


PPP-B2b INAV Messages

MT	Name	Message Contents
1	Satellite Mask	BDS mask + GPS mask + GAL mask + GLO mask
2	Satellite Orbit Correction and URA Index	(Sat Slot + IODN + IOD Corr + R + A + C + URAI) * 6
3	Differential Code Bias	#Sat + (#DCB + (Sig + DCB) * Ndcb) * Nsat
4	Satellite Clock Correction	IODP + Subtype ID + (IOD Corr + C0) * 23
5	URA Index	IODP + Subtype ID + (URAclass + URAvalue) * 70
6	Clock Correction and Orbit Correction – Combination 1	#ClockCorr + #OrbitCorr + Clock Corr * Nc + Orbit Corr * No
7	Clock Correction and Orbit Correction – Combination 2	#ClockCorr + #OrbitCorr + Clock Corr * Nc + Orbit Corr * No
8-62	Reserved	-
63	Null Message	-

BeiDou Navigation Satellite System Signal In Space Interface Control Document – Precise Point Positioning Service Signal PPP-B2b – Version 1.0, July 2020

PPP-B2b PPP Results (Kinematic PPP with only BDS-3)



Y.Liu, C.Yang and M.Zhang, Comprehensive Analysis of PPP-B2b Performance in China and Surrounding Areas, remote sensing, 2022

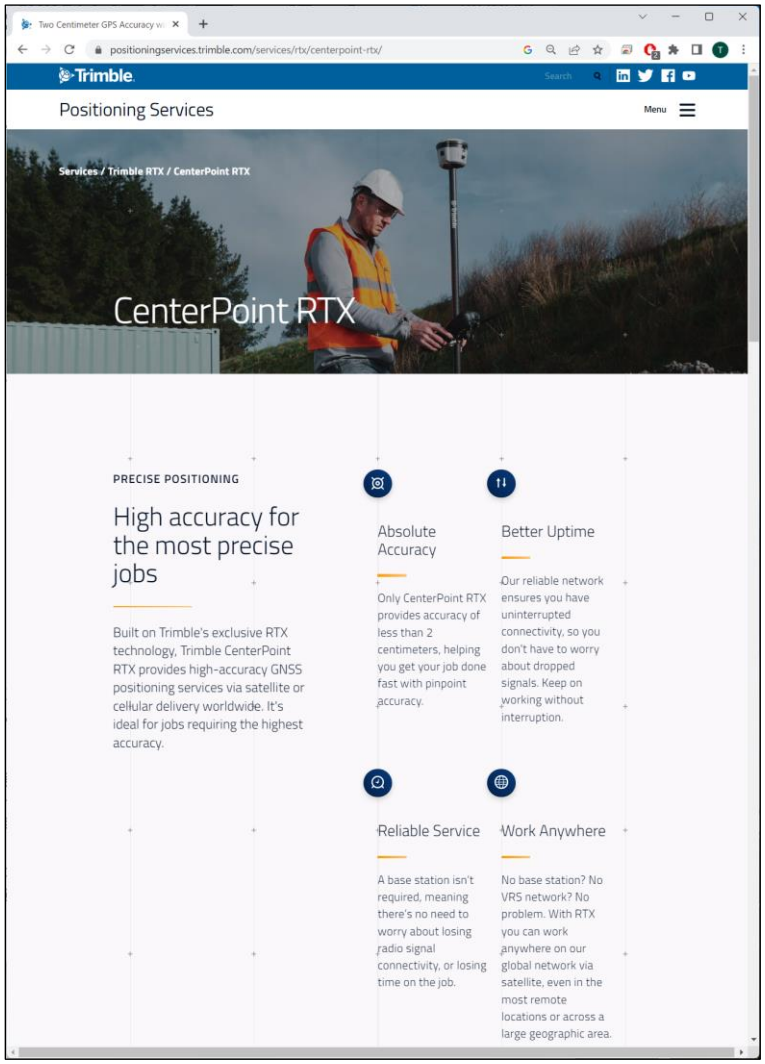
Commercial Services

Commercial Services

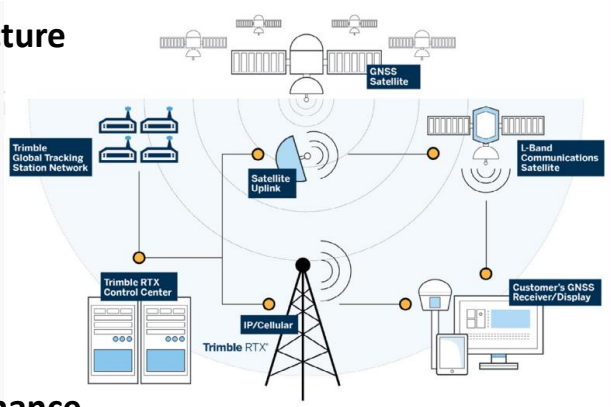
Service	Trimble CenterPoint RTX		u-blox PointPerfect	Hexagon TerraStar-C Pro	Fugro Starfix/Seastar G4	Swift Navigation Skylark
	Standard	Fast				
Correction Type	PPP-AR	PPP-RTK	PPP-RTK	PPP-AR	PPP-AR	PPP-RTK
Communication Link	GEO L-band, Internet		GEO L-band, Internet (MQTT)	GEO L-band	GEO L-band, Internet (NTRIP)	Internet (NTRIP)
Data Rate	600 ~ 2400 bps		2400 bps	?	?	?
Data Format	CMRx		SPARTN 2.0	(Proprietary)	(Proprietary)	SPARTN (?), RTCM 3
Service Area	Global	US, Canada, Europe	US, Europe, South Korea	Global	Global	US, Europa, South Korea, Japan, Australia
Target GNSS	GPS, GLO, GAL, BDS, QZS		GPS, GLO, GAL	GPS, GLO, GAL, BDS	GPS, GLO, GAL, BDS	GPS, GAL, BDS
Supported Receivers	Trimble		u-blox F9P/F9R, D9S	NovAtel OEM7	Fugro	Swift Navigation, 3rd-party Receivers
Accuracy	H 2 cm (RMS) V 5 cm (RMS)		H 3 - 6 cm (95%)	H 2.5 cm (95%) V 5 cm (95%)	H 10 cm (95%) V 15 cm (95%)	H 4 cm (50%)
Convergence Time	180 s *1 / 300 s	60 s	30 s	180 s *2 / 900 s	?	5 s (25 cm)
Subscription Price	$1,095 / year ~ $1,995 / year *3		$30 / month (L) $44 / month (L+IP)	~ $2,000 / year	?	$50 / month

*1 with Trimble ProPoint GNSS Receiver, *2 with OEM7 F/W 7.08.10 or higher, *3 in US

Trimble CenterPoint RTX



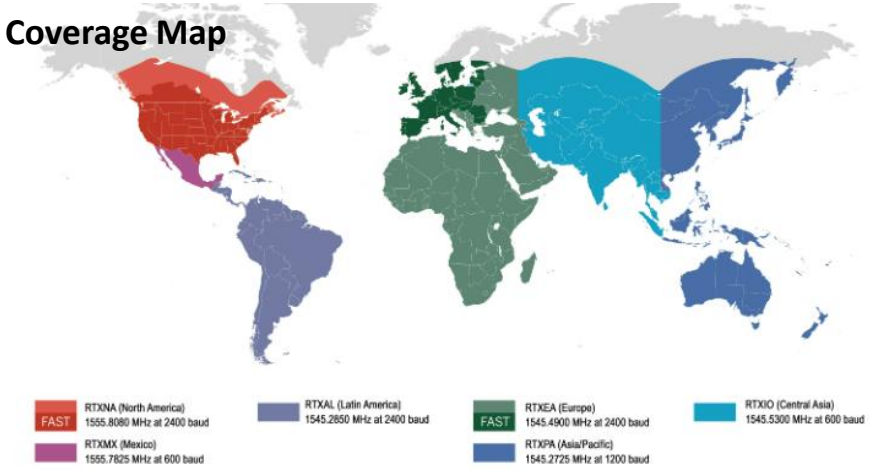
Architecture



Performance

Service	Accuracy RMS (cm)[1]	Initialization mins (Fast / Standard)[2]
CenterPoint® RTX	2 cm Horizontal 5 cm Vertical	< 1 / < 3 mins

Coverage Map



https://positioningservices.trimble.com/services/rtx/centerpoint-rtx/

u-blox PointPerfect

Product summary

PointPerfect

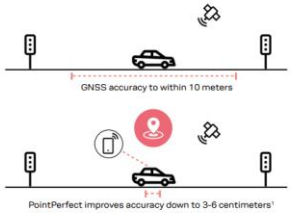
GNSS augmentation service

3-6 cm[1] accuracy and convergence within seconds

- Low bandwidth data reduces transmission cost
- Intuitive IoT services delivery platform is frictionless for business
- 99.9% uptime availability via internet and L-band satellite
- Homogeneous coverage in contiguous USA, Europe, and South Korea
- Seamless cooperation with positioning and connectivity hardware

The challenges of stand-alone GNSS

Global navigation satellite systems (GNSS) have transformed our world and enable anyone to pinpoint their location anywhere on the planet quickly and easily. GNSS provides location accuracy down to several meters, which is more than satisfactory for most applications. However, certain emerging use cases, such as autonomous vehicles, precision agriculture, or robotic lawn mowers require far higher accuracy. To achieve this, GNSS correction data is provided via mobile internet and L-band satellite signal to account for satellite clock and orbit errors and signal biases, as well as ionospheric and tropospheric influences. This, combined with the primary GNSS signal, makes it possible to improve accuracy to within centimeters.



PointPerfect overview and key benefits

PointPerfect is the u-blox high precision GNSS augmentation service that provides real-time, verified, scalable, affordable, and high-quality GNSS positioning solutions to the mass market for consumer, industrial, and automotive applications. Industry-leading positioning and connectivity hardware can now work seamlessly in combination with advanced high accuracy GNSS augmentations to deliver robustness, reliability, and end-to-end security as it relates to performance. This, in combination with an easy-to-use IoT services delivery platform, eliminates complexities and allows users to engage more efficiently and reduce time-to-market. This way, the vision of high precision GNSS positioning is brought forward to the modern age of IoT and to the realities of mass-market scale.

With mass-market scalability in mind, PointPerfect is ideally suited to the needs of industrial application areas including autonomous vehicles, such as unmanned aerial vehicles (UAV) and service robots, machinery automation, micro mobility, and other advanced navigation applications. Emerging automotive applications include automated driving (AD) and advanced driver assistance system (ADAS), lane-accurate navigation, and telematics.

High accuracy and convergence within seconds

PointPerfect's augmentation data is generated by processing data collected across a broad network of GNSS reference stations. Each reference station constantly monitors the signals broadcast by orbiting GNSS satellites to measure any effects incurred as the signals traverse the charged layers of the atmosphere. The data is processed and converted to a state-of-the-art communication protocol and broadcast through the internet and L-band satellite. The result is a GNSS correction data stream that significantly improves position accuracy to 3-6 centimeters[1] and convergence within seconds.

Low bandwidth

Modern positioning systems require a combination of low bandwidth, high accuracy, availability, reliability, and integrity of communication between service providers and end users. The SPARTN format is an open messaging standard designed to meet these requirements. SPARTN combines the advantages of state representation with modernized communication protocol fundamentals, resulting in a bandwidth-optimized solution that reduces transmitting costs for end users. PointPerfect uses a single outbound broadcast stream for all endpoints, providing efficiencies of scale for mass-market use cases.

1: 3-6 cm horizontal accuracy with a compatible receiver. Accuracy results are based on error-free GNSS observation data, complete and uninterrupted correction data reception, and ambiguity-fixed position results.

UBX-21024758 - R06

u-blox

Features / details

Technology	Advanced PPP-RTK (SSR)
Horizontal accuracy[1] (2-sigma 95%)	3-6 cm
Startup time[2]	< 30 s
Coverage	Europe, contiguous United States, and South Korea
Broadcast data format	SPARTN 2.0 - open industry format, SSR based
Data rate	Continental: 2400 bps (with reduced bandwidth options)
Standard correction rate	Satellite clock: 5 s Satellite orbits, bias, atmosphere: 30 s
Reference frame	ITRF2014 current epoch
GNSS signal support	GPS: L1 C/A, L2P, L2C, L5 GLONASS: L1 C/A, L2 C/A Galileo: E1, E5A/B
Communication methods	Mobile internet: MQTT Satellite: L-band EU and US

u-blox products supporting PointPerfect

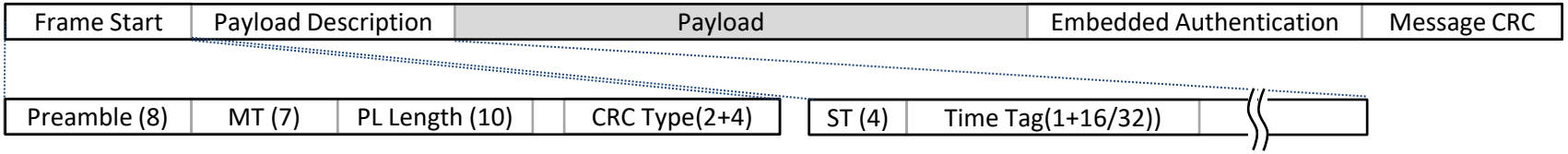
u-blox ZED-F9P high precision GNSS module
u-blox NEO-D9S correction receiver

https://www.u-blox.com/en/product/pointperfect

u-blox AG, Product summary PointPerfect GNSS augmentation service, 2022

SPARTN

SPARTN Message Frame Structure

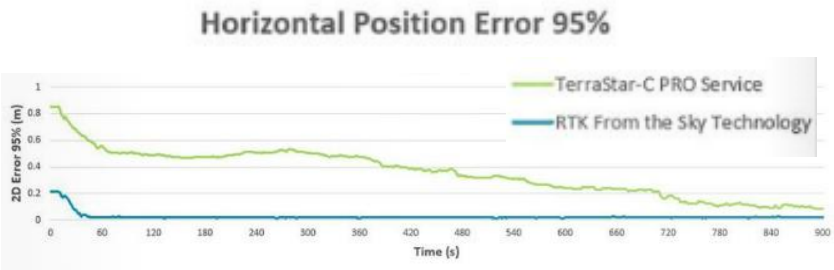


SPARTN Messages

MT	ST	ID	Name		Block Structure
0	0	SM0-0	Orbit, Clock, Bias (OCB) Message	GPS	Header + Orbit Correction (IODE + R + A + C + yaw) + Clock Correction (IODE + clock + URE) + Bias (phase mask/bias + code mask/bias)
	1	SM0-1		GLONASS	
	2	SM0-2		Galileo	
	3	SM0-3		BDS	
	4	SM0-4		QZSS	
1	0	SM1-0	High Precision Atmosphere Correction (HPAC) Message	GPS	Header + Area Data (ID + #Grid + Trop-ind + Iono-ind) + Trop Data (Trop poly-coef. + Grid-residuals) + Iono Data (Iono poly-coef + Grid-residuals)
	1	SM1-1		GLONASS	
	2	SM1-2		Galileo	
	3	SM1-3		BDS	
	4	SM1-4		QZSS	
2	0	SM2-0	Geographic Area Definition (GAD)		Header + Area definition
3	0	SM3-0	Basic Precision Atmosphere Correction (BPAC) Message		Header + BPAC Area Data + BPAC VTEC
4	0	SM4-0	Dynamic Key Message		Dynamic Key Encryption Meta Data + Dynamic Key Payload
	1	SM4-1	Group Authentication Message		#Message-ID + Authentication-type + Data-length + Message ID
120	0	SM120-0	Proprietary Messages	In-house test	-
	1	SM120-1		u-blox	(Proprietary)
	2	SM120-2		Swift Nav	(Proprietary)

Hexagon TerraStar-C Pro

Hexagon "RTK From the Sky" Technology



Simple subscriptions for the best positioning[1] Review with your NovAtel hardware details to find the best fit for your application	Horizontal Accuracy (95%)	Vertical Accuracy (95%)	Pass-to-Pass Accuracy (95%)	Convergence Time	RTK Bridging	Correction Delivery L-Band Satellite Internet	Hardware	Supported GNSS Signals
TerraStar-X[2]	2.5 cm	5 cm	2.5 cm	<1 min	Unlimited		OEM7	GPS GLO
TerraStar-C PRO[3] (Firmware prior to 7.08.10)	2.5 cm (3 cm)	5 cm (6 cm)	2.5 cm (3 cm)	3 min (15 min)	–		OEM7	GPS GLO GAL BDS
TerraStar-C	5 cm	10 cm	3 cm	<30 min	–		OEM6	GPS GLO
TerraStar-L[4]	50 cm	75 cm	15 cm	<5 min	–		OEM7 OEM6	GPS GLO
RTK ASSIST	Maintain RTK Performance				20 min		OEM7 OEM6	GPS GLO
RTK ASSIST PRO[5]	Maintain RTK Performance				Unlimited		OEM7	GPS GLO GAL BDS

TerraStar-C PRO: Fast performance with global RTK From the Sky technology

Better than ever before, TerraStar-C PRO users now experience noticeable improvements in performance including convergence time, accuracy and recovery.

Full GNSS Signal Support

GPS	L1	L2	L5	
GLO	L1	L2		
GAL	E1	E5a	E5b	E6
BDS	B1C	B2a	B2b	B3

The best performance is achievable with hardware support for all signals (full frequency, multi-constellation), on firmware 7.08.10 and higher.

Hexagon, Global Breakthrough in PPP Technology: "RTK From the Sky" – RTK accuracy and instant convergence worldwide, November 2020

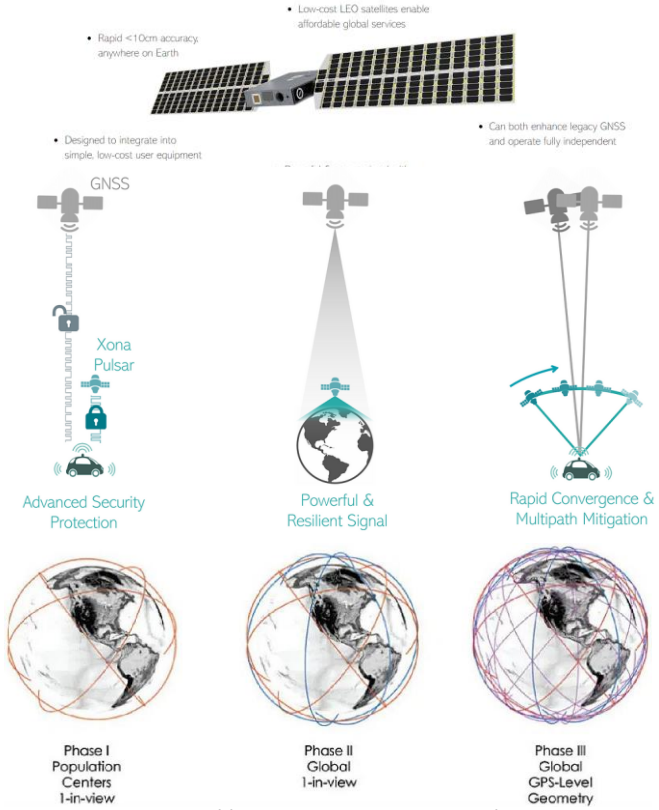
Hexagon/NovAtel, TerraStar Correction Services – Enabling accurate GNSS solutions around the world, January 2022

LEO PNT

LEO PNT

Xona Pulsar

- **Satellite constellation: LEO ~ 300 sats**
- **Phase 1: ~ 40 sats, Phase 2: ~ 70 sats**
- **First test sat “Huginn” launched in May 2022**
- **10x higher accuracy, 100x better jam resistance**
- **Rapid PPP convergence**



https://www.xonaspace.com/

Geespace GeeSAT-1

- **Satellite constellation: LEO 240 sats**
- **Phase 1: 72 sats (2025), Phase 2: + 168 sats**
- **First 9 GeeSAT-1 launched in June 2022**
- **Commercial PPP-RTK service**

Geespace Successfully Launches First Nine Satellites

June 2, 2022 |

- Inaugural launch for an expected 240 satellite constellation, with first phase of 72 satellites expected to be completed by 2025.
- Geely Future Mobility Constellation to provide services for autonomous driving, logistics, drone navigation, mapping and other fields
- Sustainably developed satellites leave no debris after designed operating lifespan
- GeeSAT-1 is China’s first modular, high-resilience, high-performance, mass-produced satellite

http://global.geely.com/media-center/news/geespace-successfully-launches-first-nine-satellites/

Future of Correction Services

Future of Correction Services

- **Open Services by GNSS**
  - **Supported by many of future GNSSs**
  - **Various promising applications by global precise positioning**
  - **Performance could be improved up to commercial service level**
- **Commercial Services**
  - **Global performance nearly same level as conventional RTK**
  - **Reduction of user (receiver and service) cost expected**
  - **Additional values (integrity, security, …) may be needed**
- **LEO PNT**
  - **Several advantages compared to existing systems**
  - **Still unclear about technical and business issues**