GNSS Precise (Point) Positioning
Where to from here?

Suelynn Choy

Co-chair ICG WG-D

Co-chair FIG WG 5.4: GNSS
Co-chair IAG WG 4.2.2: Integer Ambiguity Resolution for Multi-GNSS PPP and PPP-RTK
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Presentation Outline

1. What is Precise Point Positioning (PPP)?

2. Why is PPP useful?

3. *Food for thought* on System-Provided PPP

*"PPP conforms to the original intent of GPS usage which is single receiver positioning."*

Suelynn Choy

Precise Point Positioning (PPP)

Differential

PPP

Commercial GNSS/RNSS

IGS INTERNATIONAL GNSS SERVICE

dX, dY, dZ

X, Y, Z
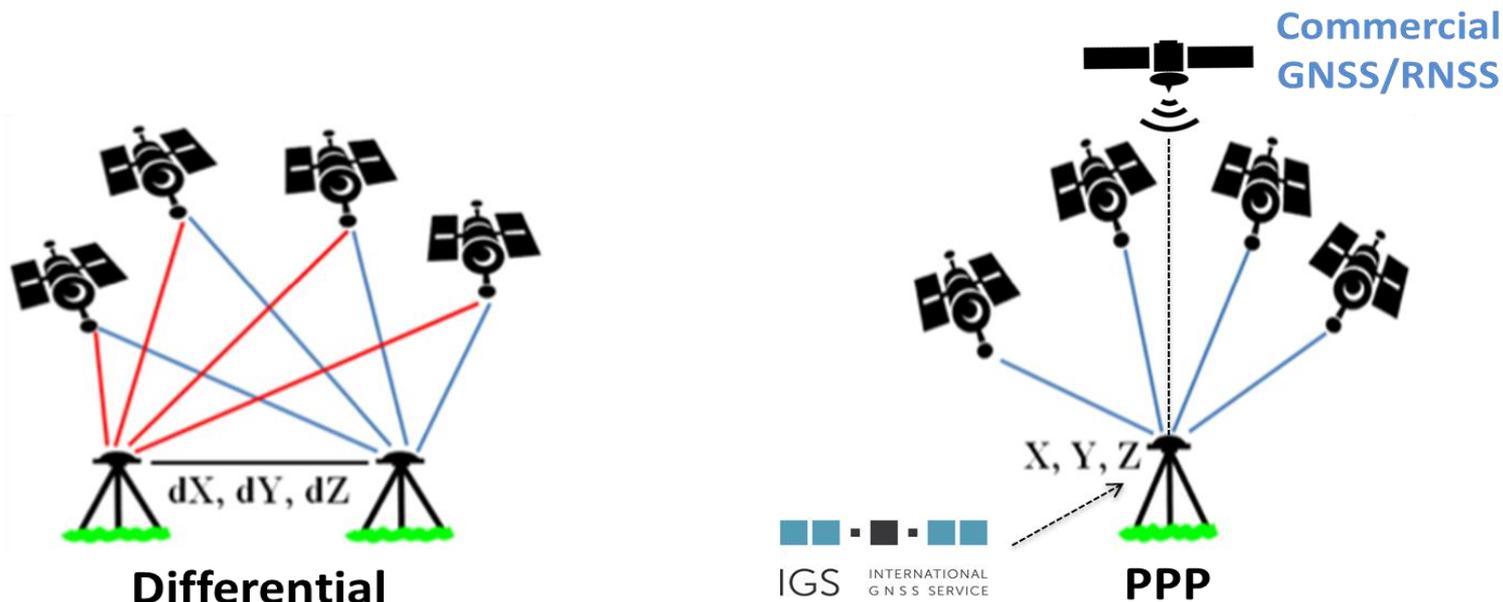
PPP uses **state space representation (SSR) correction products** such as **precise satellite orbits**, **clocks** and **signal biases** from either commercial or/and public that are delivered to the user via satellite and/or the Internet.

GNSS Correction Services

Observation State Representation (OSR)

Reference stations receive GNSS signals …
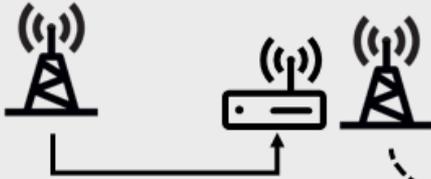
… and transfer them to the processing center.

Rovers transmit their approximate location to the processing station center …
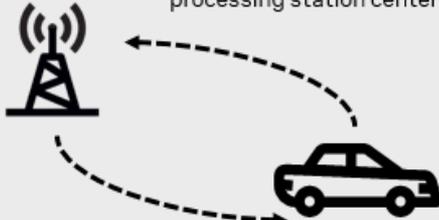
… and receive a GNSS correction stream tailored to their specific location.

State Space Representation (SSR)

Reference stations receive GNSS signals …
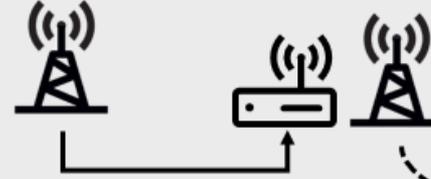
… and transfer them to the processing center.

Processing center broadcasts correction to whole continent via internet and satellite
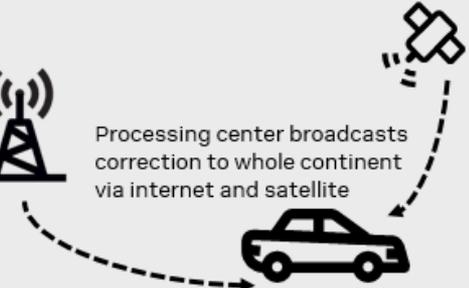
Source: Ublox

|	OSR	SSR
Corrections valid over the entire service area	✖	✔
Global coverage	✖	✔
Low bandwidth	✖	✔
One-way communication	✖	✔
Cm-level accuracy	✔	✔

PPP Service Levels

Corrections / Version	PPP (V1)	PPP-AR (V2)	SSR-RTK (V3)
Satellite orbits	✓	✓	✓
Satellite clocks	✓	✓	✓
Code biases	✗	✓	✓
Phase biases	✗	✓	✓
Ionospheric delay	✗	✗	✓
Tropospheric delay	✗	✗	✓

PPP Service Levels

Performance / Version	PPP (V1)	PPP-AR (V2)	SSR-RTK (V3)
Accuracy	10-20 cm	5-10 cm	5 cm
Convergence time	30-50 mins	~ 30 mins	< 10 mins*

24 hr rms (mm)	Horizontal	Vertical
Float	6.2	10.9
Fixed	5.6	10.8

PPP	Horizontal	Vertical
Convergence < 10 cm / 20 cm	00:40:45	00:37:28
RMS after convergence (cm)	4.8	11.6
STD after convergence (cm)	2.4	2.4

PPP+Iono	Horizontal	Vertical
Convergence < 10 cm / 20 cm	00:00:37	00:09:10
RMS after convergence (cm)	2.3	5.9
STD after convergence (cm)	2.2	5.9
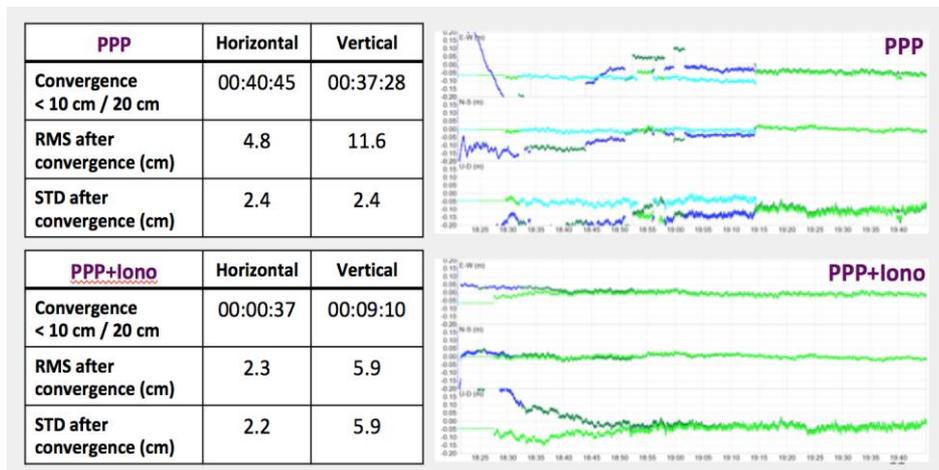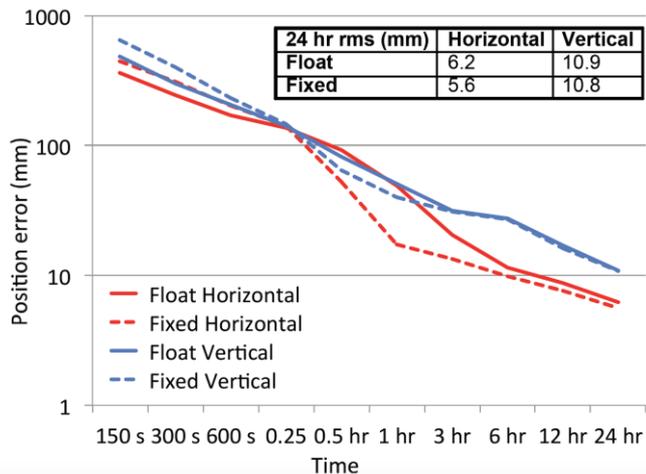
Uses of PPP

PPP is particularly **feasible** for positioning and navigation in **remote areas** or regions of **low GNSS reference stations**

"High precision GNSS is no longer "special".

It is becoming mainstream."

Matt Higgins

Mass Markets: From Autonomous Systems to LBS

Teseo-LIV3F module
GNSS solution for Industrial and IoT

Source: STMicroelectronics

ST

u-blox F9 takes GNSS precision to the next level

- Centimeter-level accuracy
- Fast TTFF
- Multi-constellation and multi-band
- Global coverage
- Dead reckoning
- Highest security

ublox F9

- Commercial UAV
- Ground robotics navigation
- Lane-level navigation
- Heavy machine navigation
- Industrial navigation and tracking

Source: Ublox

BOSCH

Geo++

MITSUBISHI ELECTRIC
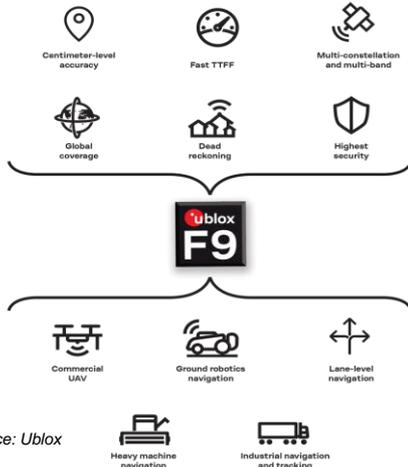
ublox

Sapcorda.

Sapcorda Services will bring high precision GNSS positioning services to mass markets

Source: GPS World

Dual-band GNSS market moving from insignificant to billions in less than 5 years

December 6, 2018 - By GPS World Staff   0 Comments   Est. reading time: 2:30

- Android 5.1 system on Quad-core 64bits CPU
- Up to 2cm accuracy L1 GNSS RTK
- Works as Rover or Base Station
- Supports WiFi / BT / 4G LTE multiple data networks
- Supports majority of GIS & Land Survey app
- IP65, 1.2m drop, rugged design for field work

Source: DataGNSS

VEHICLE TO WORLD
We provide automotive-grade GNSS solutions to smart driving, V2X, TBOX and etc.

Source: Allystar

Worldwide NRTK Solution
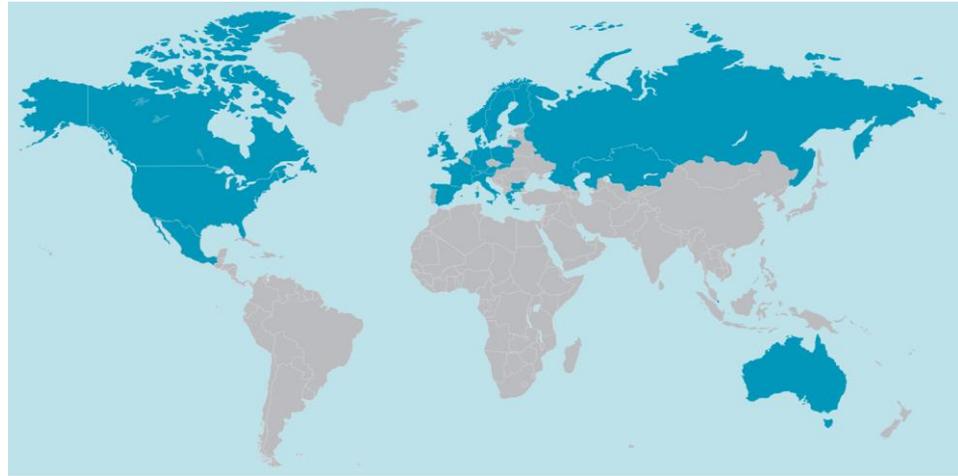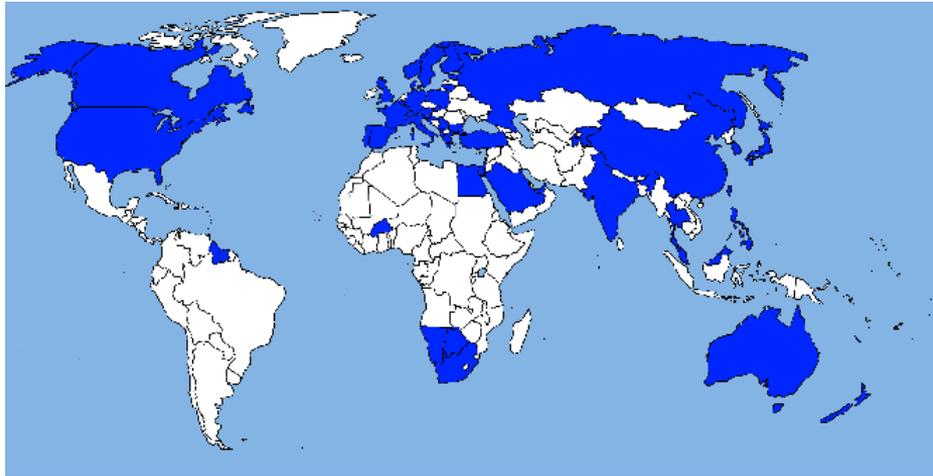
PPP Commercial Services

Provider	Service	Type	Area	Delivery	GNSS[1]	Solution	Accuracy (95%) Horizontal	Accuracy (95%) Vertical	Convergence time	Notes
Trimble / OminSTAR	VBS	Commercial	Global	L-Band	G	WADGNSS	< 1 m	NA	< 1 min	
	XP			L-Band	G	PPP	15 cm	NA	< 45 min	
	G2			L-Band	G+R	PPP-AR	< 10 cm	NA	< 20 min	
	HP			L-Band	G	PPP-AR	10 cm	NA	< 45 min	
Trimble	Viewpoint RTX	Commercial	Global	L-Band, Internet	G+R+E+B+J	WADGNSS	< 1 m	NA	< 5 min	
	Rangepoint RTX			L-Band, Internet	G+R+E+B+J	PPP	< 50 cm	NA	< 5 min	
	Fieldpoint RTX			L-Band, Internet	G+R+E+B+J	PPP	< 20 cm	NA	< 1 min / 15 min	
	Centerpoint RTX			L-Band, Internet	G+R+E+B+J	SSR-RTK	< 2.5 cm	NA	< 2 min / < 20 min	
Fugro	Starfix.G2+	Commercial	Global	L-Band, Internet	G+R	PPP-AR	< 3 cm	< 6 cm		
	Starfix.G4+			L-Band, Internet	G+R+E+B	PPP-AR	< 3 cm	< 6 cm		
	Starfix.G4			L-Band, Internet	G+R+E+B	PPP	< 10 cm	< 10 cm		
	Starfix.G2			L-Band, Internet	G+R	PPP	Sub-decimetre	NA		
	Starfix.XP2			L-Band, Internet	G+R	PPP	< 10 cm	< 20 cm		Third party corrections
	Starfix.HP		Regional	L-Band, Internet	G	WADGNSS	10 cm	NA		Differential technique (L1 & L2)
	Starfix.L1			L-Band, Internet	G	WADGNSS	< 1.5 m	NA		Single frequency code (L1)
NavCom	StarFire	Commercial	Global	L-Band, Internet	G+R	PPP	< 5 cm (68%)	< 10 cm (68%)	~30-45 min	
Novatel	CORRECT SBAS	Commercial	Global	L-Band, Internet	G	WADGNSS	60 cm (68%)	NA		SBAS dependent
				L-Band, Internet	G+R	PPP	40 cm (68%)	60 cm	< 5 min	TerraStar-L
	CORRECT PPP			L-Band, Internet	G+R	PPP-AR	4 cm (68%)	6.5 cm (68%)	30-45 min	TerraStar-C
				L-Band, Internet	G+R+E+B	PPP-AR	2.5 cm (68%)	5 cm (68%)	< 18 min	TerraStar-C PRO
Hexagon AB	TerraStar	Commercial	Global	L-Band, Internet	G+R	PPP-AR	5 cm	NA	15-45 min	
	TerraStar X			L-Band, Internet	G+R	SSR-RTK	5 cm	NA	< 1 min	
Hexagon AB	Veripos Apex	Commercial	Global	L-Band, Internet	G	PPP	5 cm	12 cm		Apex is based on Veripos OCDS/network
	Veripos Apex[2]			L-Band, Internet	G+R	PPP	5 cm	12 cm		
	Veripos Apex[5]			L-Band, Internet	G+R+E+B+J	PPP	5 cm	12 cm		
	Veripos Ultra			L-Band, Internet	G	PPP	< 10 cm	< 20 cm		Ultra is based on JPL OCDS/network
	Veripos Ultra[2]			L-Band, Internet	G+R	PPP	< 10 cm	< 20 cm		
	Veripos Standard			L-Band, Internet	G	WADGNSS	1m	NA		
	Veripos Standard[2]			L-Band, Internet	G+R	WADGNSS	1m	NA		Single-frequency
Hemisphere	Atlas Basic	Commercial	Global	L-Band, Internet	G+R+B	WADGNSS	1 m	NA		
	Atlas H30			L-Band, Internet	G+R+B	PPP	30 cm	NA		
	Atlas H10			L-Band, Internet	G+R+B	PPP-AR	8 cm	NA		
Topcon	TopNET Live	Commercial	Global	L-Band	G+R+B+J	PPP	< 20 cm	NA		
Swift Navigation	Skylark	Commercial	Local*	Internet	G+R+B+J	SSR-RTK	cm		In seconds	Cloud-based RTK correction service
GÉOFLEX	GÉOFLEX	Commercial	Global	Internet	G+R+E+B	PPP-AR	4 cm		> 30 min	Based on CNES PPP Wizard
Spaceopal	NAVCAST (beta)	Commercial	Global	Internet	G+E	PPP				Based on DLR Reticle
SAPCORDA	SAPCORDA	Commercial	Global	Internet		PPP				Joint venture between GEO++, MELCO, Ublox & Bosch
Qianxun SI	"Universe Voice Plan"	Commercial	Global	L-Band, Internet	G+R+E+B	PPP/ SSR-RTK				
GPAS^	MADOCA	Commercial	Global	Internet	G+R+J	PPP-AR				Aiming to commercialize global High precision positioning service. Currently in experimental phase

[1] GNSS Constellations: GPS (G), GLONASS (R), Galileo (E), BeiDou (B), QZSS (J)

* Skylark is currently available in the contiguous United States of America with plans for Europe, Asia and eventually, global expansion.

^ Global Positioning Augmentation Service Corporation (GPAS) is a joint venture between Hitachi Zosen Corporation, Development Bank of Japan, Denso Corporation, Hitachi Automotive Systems, Japan Radio Co., NEC Solution Innovators and Furuno Electric.

Note that not all companies list the accuracy confidence level. Some mention a 1-sigma level (corresponding to 68 %), and others mention a 95 % confidence (corresponding to 2-sigma). The accuracy values shown in this table are the accuracies reported by the companies and do not refer to values resulting from independent research.

"A place where competitors become colleagues."

Christopher Hegarty

PPP Augmentation Signals via GNSS

| System	SV Orbit	Augmentation Signal for PPP	Frequency (MHz)	Bandwidth (bps)
Galileo	MEO	E6	1278.75	500
GLONASS	MEO	?	?	?
BeiDou-3	GEO	B2b	1207.14	1000
QZSS	IGSO and GEO	L6D, L6E	1278.75	2000
Australia^	GEO	L1 L5	1575.42 1176.45	250 250

^ Based on the Australian SBAS Testbed.

India and Africa as well!

GNSS PPP Service Characteristics

System	Coverage	Format	Supported GNSS/RNSS	Service
Galileo	Global	Open	?	?
GLONASS	Global	Commercial ?	?	?
BeiDou-3	Regional	Open	?	?
QZSS	Regional	Open	GPS, QZSS, GLO & GAL	PPP-AR SSR-RTK (JAP)
Australia^	Regional	Open	GPS & GAL	PPP-float

* PPP-float: Standard float ambiguity PPP
   PPP-AR: Ambiguity resolved PPP
   SSR-RTK: RTK based on state space representation method

Source: FIG Presentation by Choy, Lilje and Higgins, ICG13, Xi'an, China, November 2018

PPP Service Levels

PPP (V1) – Standard PPP	PPP-AR (V2) – Better accuracy	SSR-RTK (V3) – Fast convergence
Accuracy: **10 - 20 cm** Algorithm: Float ambiguities Convergence time: **~ 30-50 min**	Accuracy: **5 - 10 cm** Algorithm: Fixed ambiguities Convergence time: **~ 30 min**	Accuracy: **5 cm** Algorithm: RTK using SSR methods Convergence time: **< 10 min^**
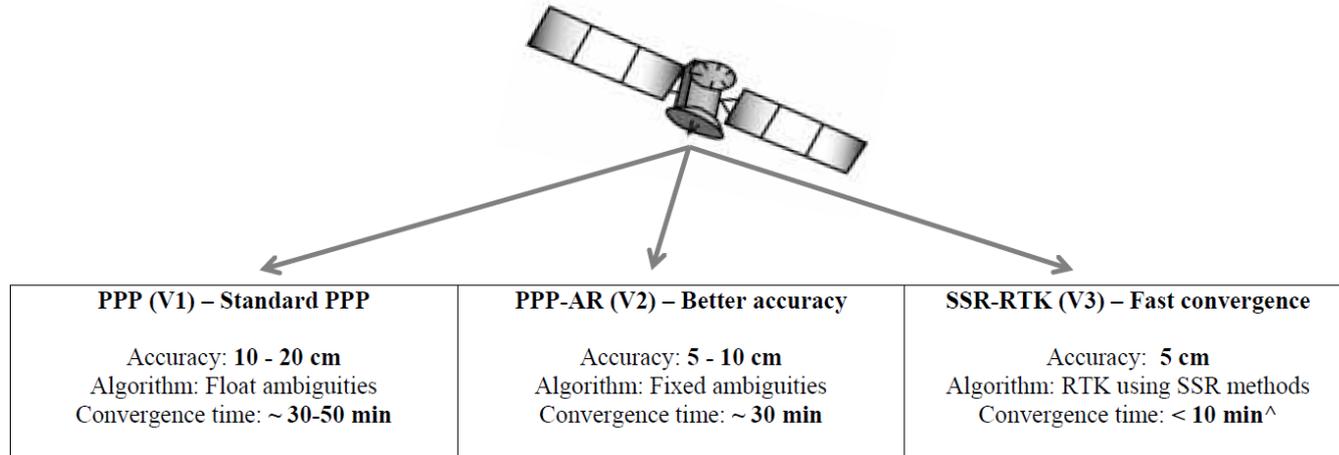
^ Convergence time depends on the accuracy of the ionospheric (and tropospheric) corrections.

For consideration:

(1)   **The number of GNSS constellations** covered could be a differentiator for the definition of the different services.

(2)   Typically two carrier phase signals (e.g., L1+L2 / E1+E5) are used in PPP. **The number of GNSS signals** covered could be a differentiator for the definition of the different services.

For Consideration - Users

What will it enable us to do?

- **Service**

~ A\$3000/yr

Free

- **Hardware**

> A\$6000

< A\$150
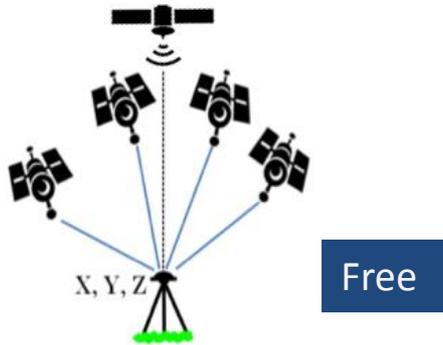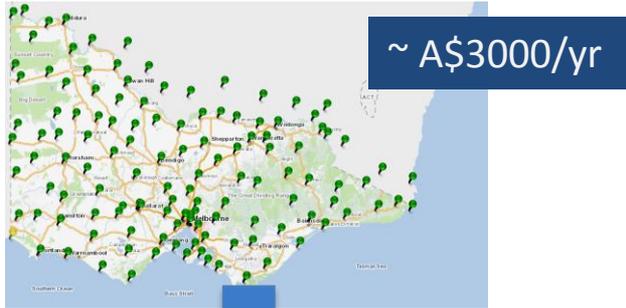
For Consideration – System Providers

To ease interoperability with other system provided PPP services and facilitate **service penetration** at the user level, Providers are encourage to consider:

1. **Carrier frequency channel for PPP service transmission**
   - Candidate signals: L5/E5A, E5b/B2b, E6/L6
   - Discussion to also include SBAS IWG wrt to L5/E5a, E5b bands
   - E6/L6 is not protected and subject to interference. Proposal to ITU?
   - Frequency selection depends on the market to be addressed

2. **PPP signal structure, modulation and encoding strategy**

Consistent with the **principle of transparency** in the provision of open services, Providers are encouraged to publish and disseminate necessary information (eg., WG-S Interoperability and Service Standards Subgroup).

3. **Publish and disseminate PPP signal and system information, i.e.,**
   - Interface Specification Document
   - Service Level Information/Definition
   - PPP Performance Standard

Recommendation in ICG-14?

Proposal: Establish a System Provided PPP Interoperability Task Force/Sub-Group/Correspondence. This group will:

- Encourage coordination amongst Providers to ensure greater compatibility, interoperability, and transparency.
- Ensure the impact on existing services already available on the signals to be carefully assessed, discussed, and agreed.
- Coordinate and work with the SBAS IWG on frequency channel recommendation for PPP service in particular to do with L5/E5a and E5b ARNS bands.
- Coordinate with ITU re- proposal to clean E6/L6 ?
- Promote common terminology and definition in individual PPP open service specifications.
- Each individual Provider may consider using in their publication of signal and system information, the policies of provision, and the minimum levels of performance offered for their PPP service.
- Coordinate, promote and encourage utilisation of System Provided PPP services.
- This group will be co-chaired by System Providers.

Questions ?

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