Compact multi-GNSS PPP corrections messages for transmission through a 250 bps channel

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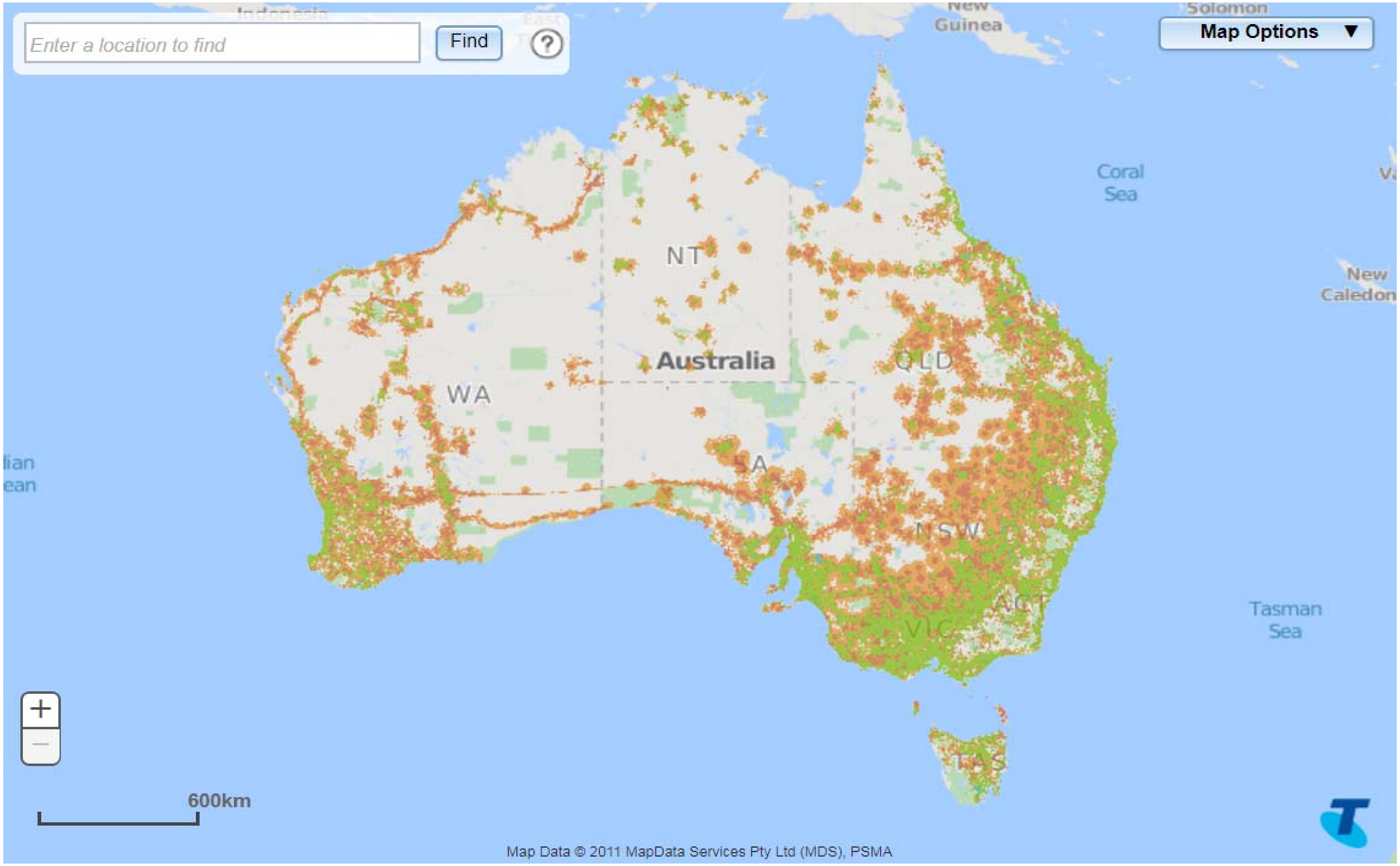
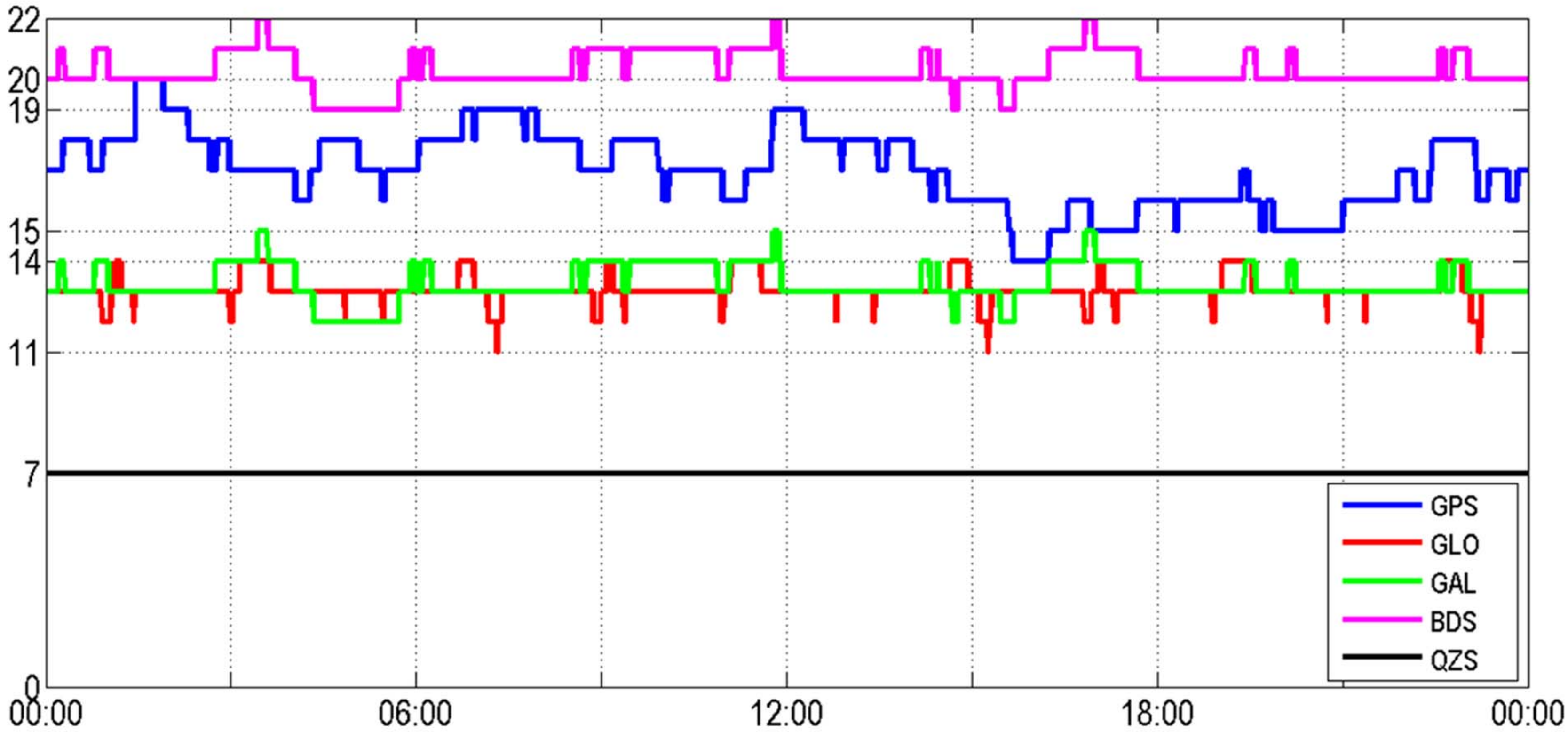
- Compact messages for multi-GNSS PPP
- Performance of PPP corrections

Precise Point Positioning

- Wide area alternative for high accuracy GNSS positioning



Advances in PPP



Number of satellites visible in Australia (BDS includes GEO, IGSO and MEO)

- Multi-GNSS: GPS, GLONASS, Galileo, Beidou, QZSS, NAVIC
- Multi-frequency: L5/E5a, E5b/B2, E6/B3
- Ionosphere corrections

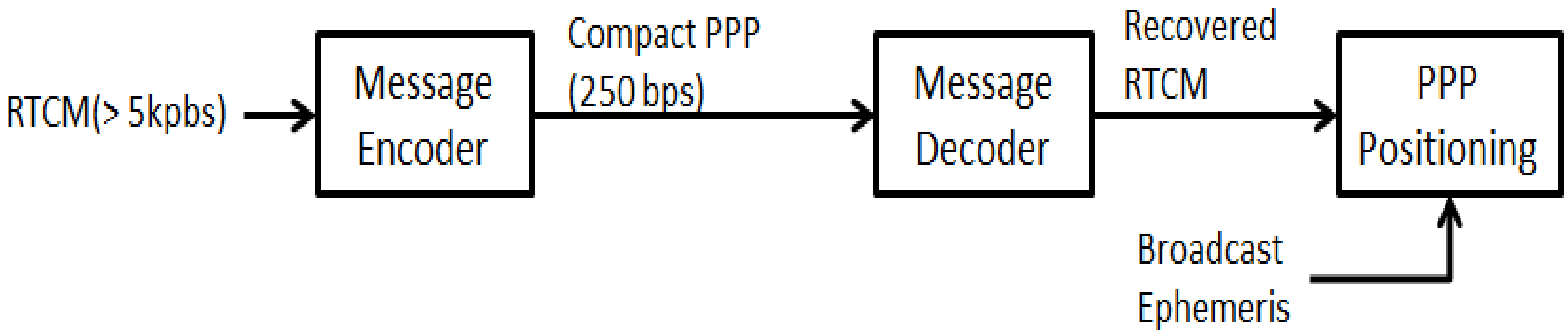
Increasing Bandwidth Requirements

Satellite channels for GNSS Augmentation

- Legacy SBAS channels: WAAS, EGNOS, MSAS, Inmarsat
- Augmentation channels in GNSS: QZSS L1S, L5S & L6, Galileo E6
- Commercial channels: Iridium (2.4 kbps), Inmarsat BGAN (>4kbps)

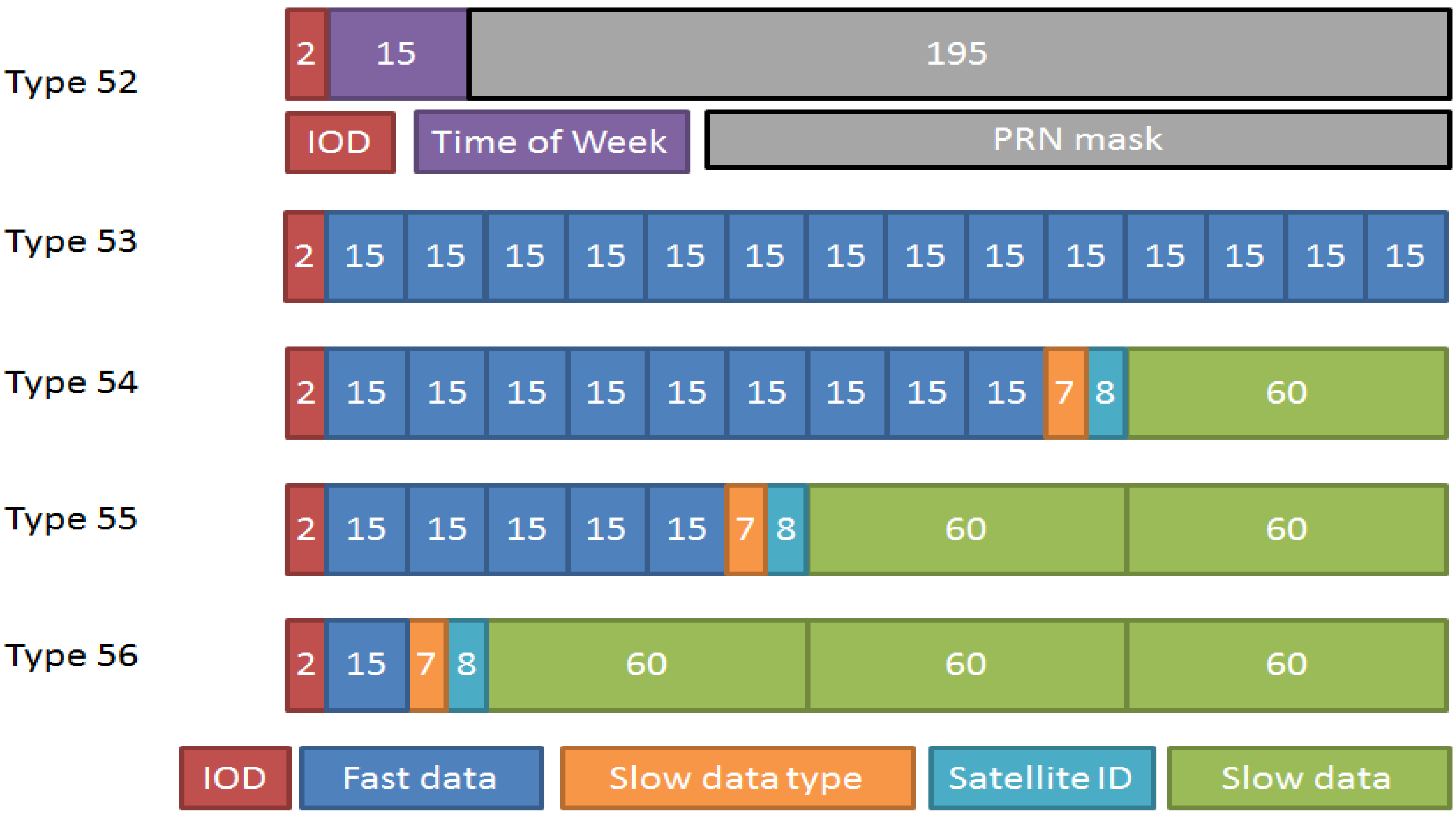
Channel	Carrier freq.	Total data rate	Effective data rate
L1 SBAS	1575.42 MHz	250 bps	212 bps
L5 SBAS	1176.45 MHz	250 bps	216 bps
Galileo CS	1278.75 MHz	500 bps	448 bps
QZSS L6	1278.75 MHz	2000 bps	1695 bps

Compact PPP transmission test



- Real-time stream for PPP compacted:
  - CNES's CLK93
  - JAXA's MDC1F
- Broadcasted through NTRIP Caster:
- Used with ALIC CORS observables for PPP

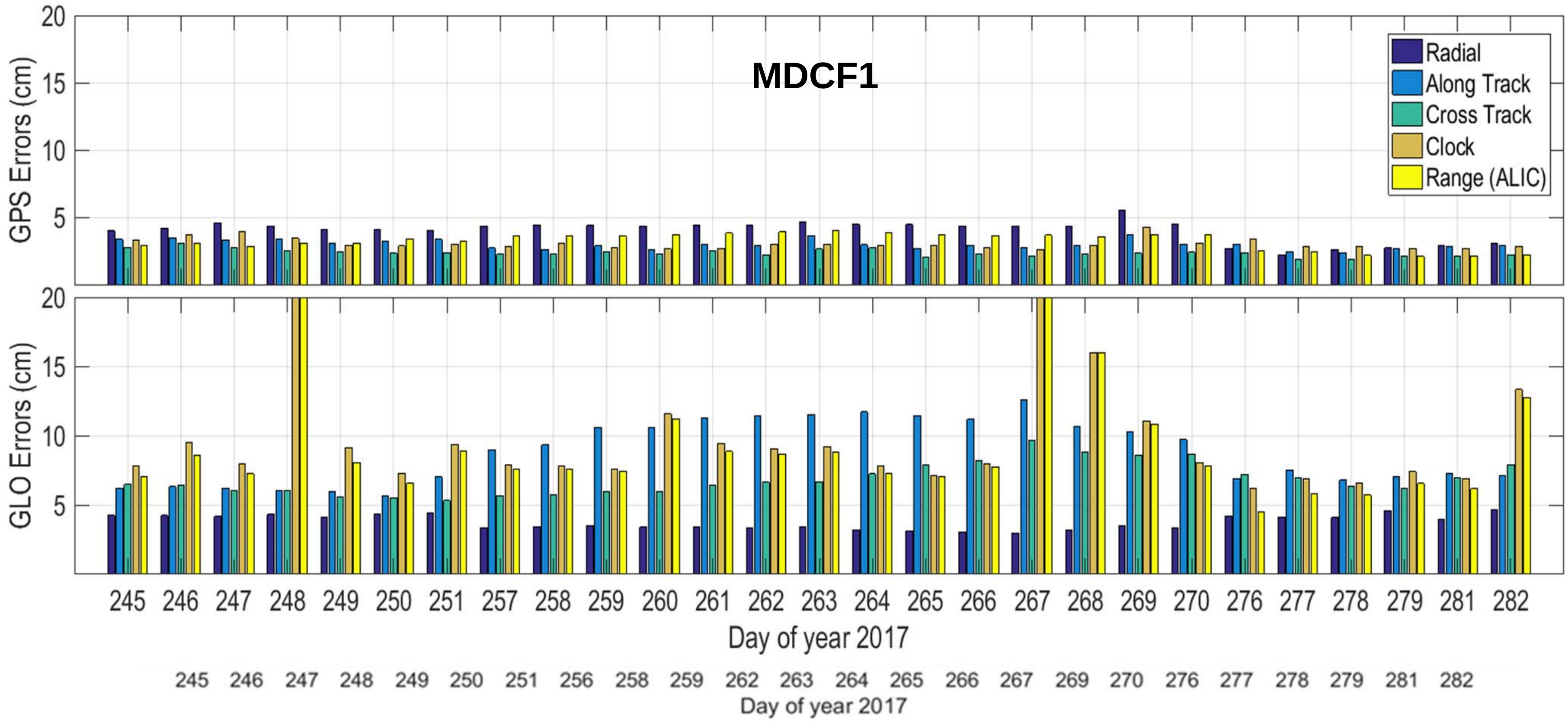
Multi-GNSS PPP encoding



PPP processing

Measurements	GPS, GLO, GAL	GPS, GLO
Rec. position	Random variable (σ = 100 m, μ = SPP sol.)	
Rec. Clock	Random variable (σ = 100 m, μ = SPP sol.)	
Rec. phase bias	Random walk (σ = 10^{-5} m/sec)	
Troposphere	ZWD= Random walk (σ = 10^{-5} m/sec) ZHD = Deterministic	
Ionosphere	Ionosphere-free combination	
Ambiguities	Constant AR for GPS only	Constant

RTCM correction streams



- CLK93: GPS, GLO, GAL, BDS; 5 sec UDI
- MDCF1: GPS, GLO, QZSS; 1 sec UDI

Product degradation due to compact messaging

	CLK93 RTCM	CLK93 Compact	MDC1F RTCM	MDC1F Compact
GPS Orb	3.18 cm	3.17 cm	4.03 cm	4.12 cm
GPS Range	2.95 cm	3.41 cm	3.27 cm	3.92 cm
GLO Orb	3.79 cm	4.25 cm	4.06 cm	4.23 cm
GLO Range	9.99 cm	10.34 cm	10.28 cm	10.45 cm
GAL Orb	5.37 cm	5.32 cm	-	-
GAL Range	11.81 cm	11.56 cm	-	-
Data rate	6.4 kbps	250 bps	22.4 kbps	250 bps

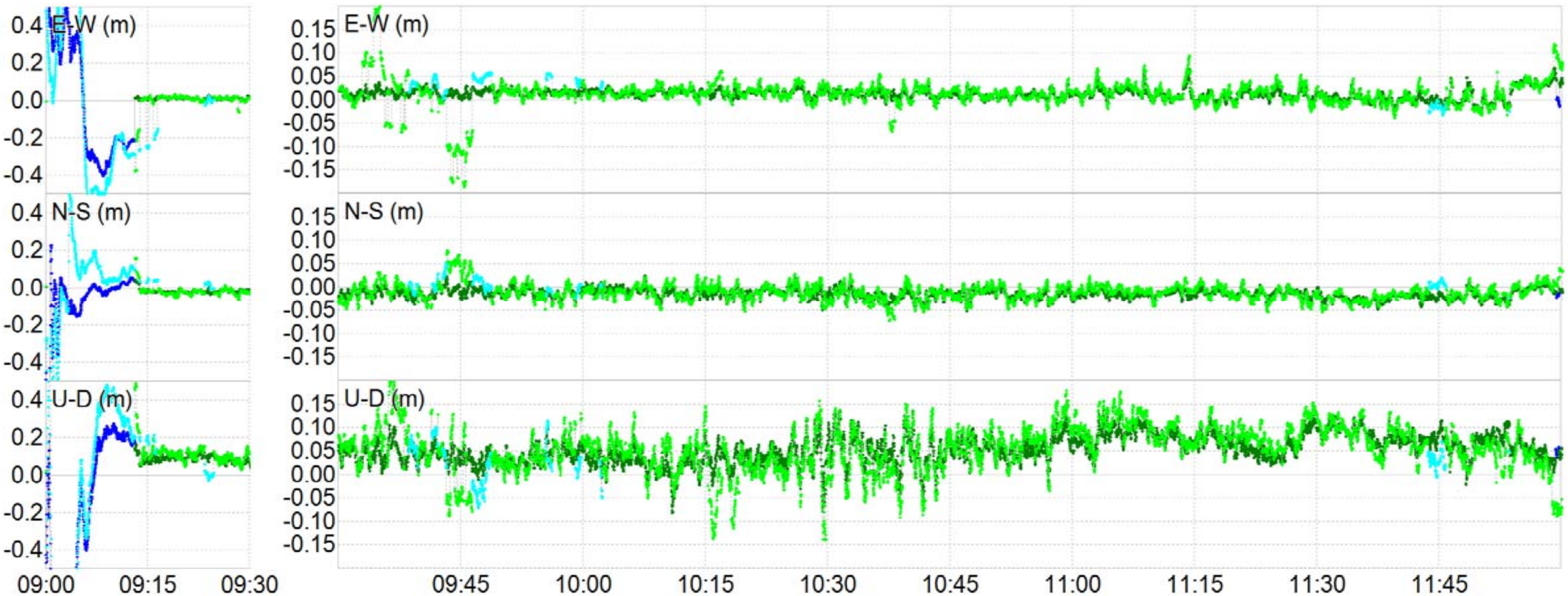
- RMS difference to IGS final
- Major degradation seem in the clock correction for GPS
- SISRE degradation of 16% for CLK93, 19% for MDC1F

Channel occupancy in 250bps frame

- CLK93: Included corrections for an average of 74.4 satellites
- MFC1F: Included corrections for an average of 49.4 satellites
- Total channel occupancy was less than 60% for both cases

	CLK93		**MDCF1**	
	Data rate	Occupancy	Data rate	Occupancy
Overhead	46.0 bps	18.4%	54.6 bps	21.8%
High rate clock	46.8 bps	18.7%	53.7 bps	21.5%
Ephemeris	37.2 bps	14.9%	24.7 bps	9.9%
Signal bias	10.1 bps	4.0%	6.7 bps	2.7%
Free fields	7.3 bps	**2.9%**	84.9 bps	**34.0%**
Null messages	102.6 bps	**41.0%**	25.4 bps	**10.2%**

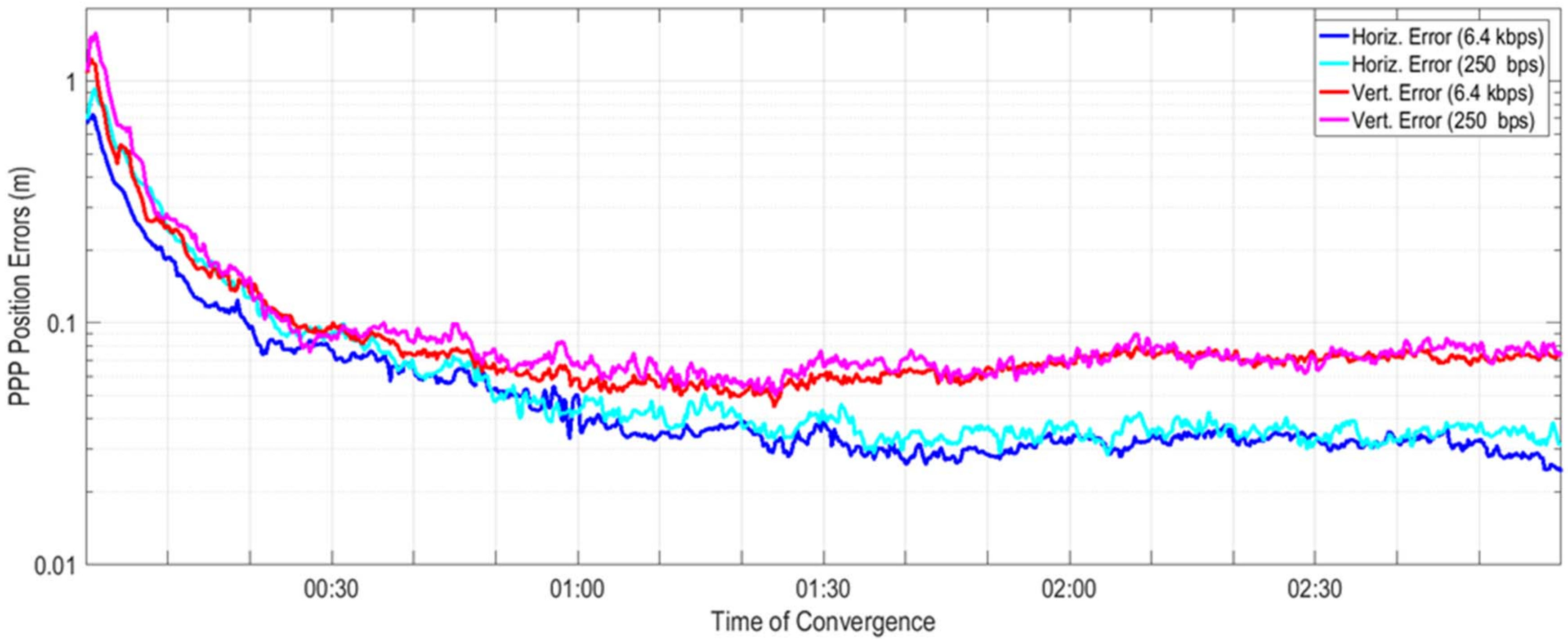
PPP performance with compact PPP messages



Time series of PPP errors using the original (dark blue/green) and compact (light blue/green) messages. Blue dots represent solutions without solved anbiguities, green solution ambiguity solved PPP.

- Convergence times increase by about 17% for horizontal and 30% in vertical solutions.
- Once solutions have converged, difference between original and compact message based solutions are millimeter level for horizontal, few centimeter for vertical

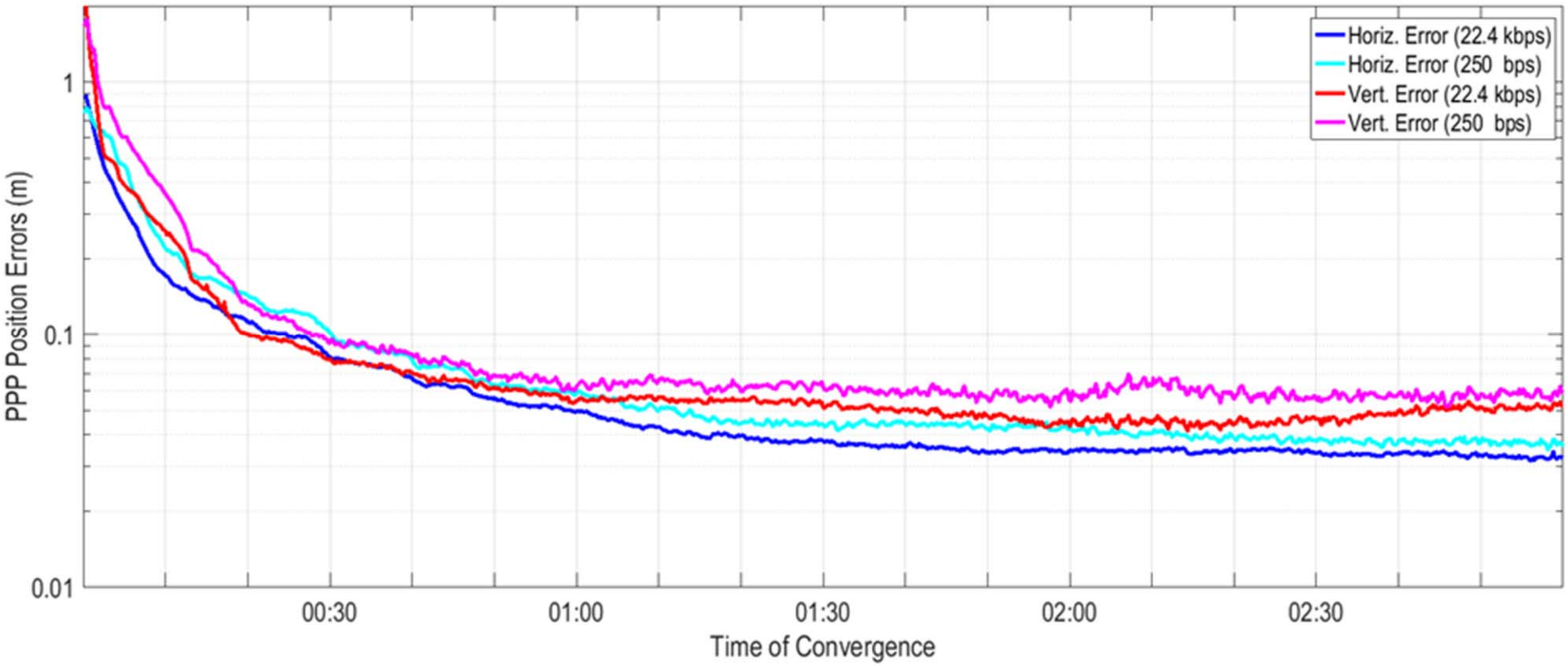
PPP performance with CLK93 based messages



RMS of horizontal (blue) and vertical (red/pink) errors using original (dark blue/ red) and compact (light blue/ pink) messages. September 22 to October 10, 2017

	Horz. <10cm	Vert. <10cm	Horz. RMSE	Vert. RMSE
CLK93 RTCM	19min 40sec	25min 20sec	3.25cm	6.57cm
CLK93 250bps	23min 00sec	36min 20sec	3.69cm	6.95cm

PPP performance with MDC1F based messages



RMS of horizontal (blue) and vertical (red/pink) errors using original (dark blue/ red) and compact (light blue/ pink) messages. September 2 to September 21, 2017

	Horz. <10cm	Vert. <10cm	Horz. RMSE	Vert. RMSE
MDC1F RTCM	24min 50sec	18min 50sec	3.64cm	4.95cm
MDC1F 250bps	27min 00sec	26min 50sec	4.28cm	5.98cm

Summary

- Satellite delivered PPP has the potential to become an important positioning infrastructure.
- Developments in PPP: Multi-GNSS, Multi-Frequency, Ionosphere correction has the potential will require increased bandwidth
- Compact messages for multi-GNSS PPP were tested
- Orbit, clock and signal biases for 50-70 satellites were fit in less than 60% of a 250bps channel
- Accuracy degradation was 13%, and convergence time 17% longer. Still within 5 cm RMSE horizontal, 10 cm RMSE vertical position
- Corrections for close to 100 satellites may be fit in a 250bps channel

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* **Disclaimer:** Any opinions expressed in this presentation are solely the first author's and do not necessarily represent those of these organizations listed herein.

Thank you