Performance of Real-Time Precise Point Positioning Using MADOCA-LEX Augmentation Messages

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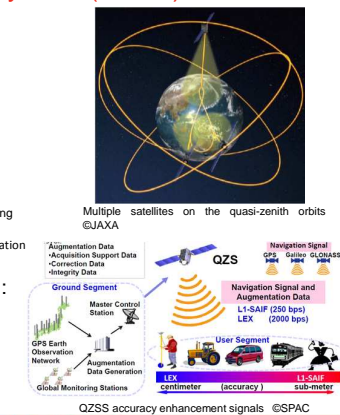# QZSS and LEX Signal

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Outline

- Introduction
  - QZSS and LEX signal
  - MADOCA correction messages

- Real-Time PPP Tests
  - Fixed point (static & kinematic)
  - Vehicle (kinematic)

- Summary and Future Work

Note: QZSS – Quasi-Zenith Satellite System
LEX – L-band EXperimental
MADOCA – Multi-GNSS Advanced Demonstration tool for Orbit-and-Clock Analysis
PPP – Precise Point Positioning

Quasi-Zenith Satellite System (QZSS)

- Functional Capability:
  - GNSS Complementary
  - GNSS Augmentation
  - Messaging Service

- Coverage:
  - East Asia and Oceania

- Signals:
  - L1C/A, L1C, L2C and L5 → positioning
  - L1-SAIF on 1575.42 MHz → augmentation
  - **LEX on 1278.75 MHz**

- First QZSS Satellite 'Michibiki':
  - Launched in September 2010

- Future QZSS Satellites:
  - 2 HEO and 1 GEO
  - End of March 2018

Multiple satellites on the quasi-zenith orbits ©JAXA

QZSS accuracy enhancement signals ©SPAC

QZSS LEX Signal

- LEX (L-band EXperimental) signal:
  - Frequency: 1278.75 MHz (similar to Galileo E6)
  - Message rate: 2 Kbps
  - For high accuracy (cm-level) positioning applications, e.g. Precise Point Positioning (PPP)

Message Streams	Frequency	Encoding	Bit rate
GPS NAV messages	L1 (1575.42 MHz)	BPSK	50 bps
SBAS messages	L1 (1575.42 MHz)	BPSK	250 bps
Galileo C/NAV	E6 (1278.75 MHz)	BPSK	500 bps
QZSS LEX messages	E6 (1278.75 MHz)	CSK	2000 bps

MADOCA Correction Messages

Note: MADOCA – Multi-GNSS Advanced Demonstration tool for Orbit-and-Clock Analysis


LEX Signal Coverage
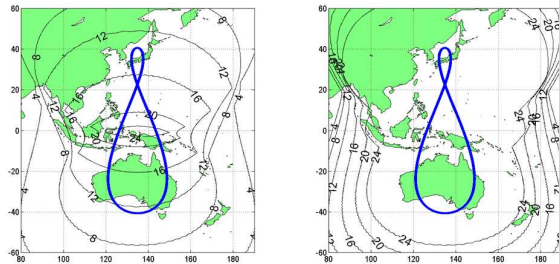
- QZSS orbits (Blue):
  - Central longitude: 135° E; Orbit inclination 43°
- Left: current coverage (2014)
  - 12 hours a day or more
- Right: coverage with 3 HEO satellites (2018)
 - 24 hours a day

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MADOCA Message Structure

- RTCM (Radio Technical Commission in Maritime Services) messages into LEX message frames
  - RTCM 3.2 messages for State Space Representation (SSR) corrections are packaged
  - LEX message type 12
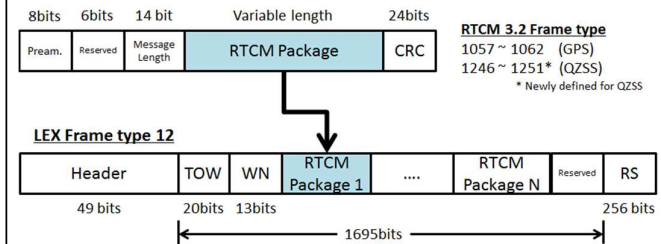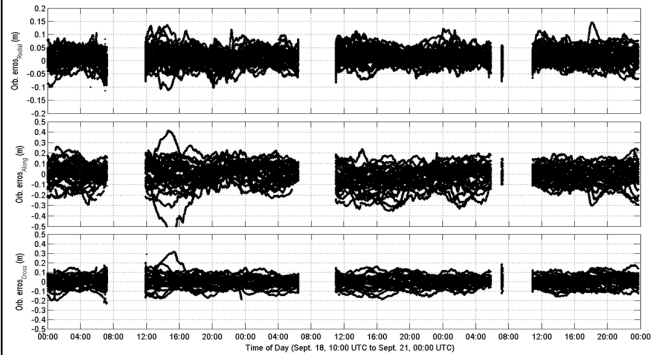
MADOCA Message Content (Oct 2013)

Message Data	Broadcast Rate	Update Interval	Effective Period
URA	10 seconds	10 seconds	30 seconds
Satellite Orbit	10 seconds	10 seconds	30 seconds
Satellite Clock	2 seconds	2 seconds	2 seconds
Code Bias	10 seconds	10 seconds	10800 seconds

MADOCA Clocks
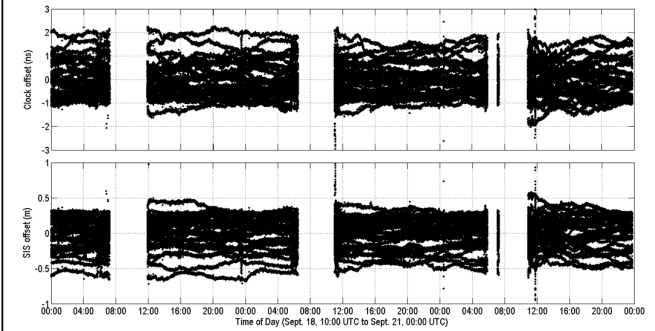
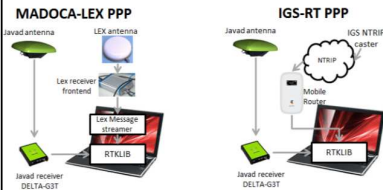- RMS clock errors: 0.762 ns

MADOCA Orbits

- RMS orbit errors: 3.6 cm (radial), 10 cm (along-track), 5.9 cm (cross-track)

MADOCA-LEX PPP
Fixed Point Test (Static & Kinematic)

Slide 1: Real-time PPP: Fixed Point Test

- **Static point:**
  - RJAP, RMIT University

- **Reference coordinates:**
  - Post-processed PPP (NRCan-PPP)
  - ITRF08

- **Real-time corrections:**
  - MADOCA-LEX
  - IGS-RTS (CLK11)

Diagram labels:
MADOCA-LEX PPP — Javad antenna, LEX antenna, Lex receiver frontend, Lex Message streamer, RTKLIB, Javad receiver DELTA-G3T

IGS-RT PPP — Javad antenna, IGS NTRIP caster, NTRIP, Mobile Router, RTKLIB, Javad receiver DELTA-G3T

Slide 2: Real-time PPP: Kinematic, Fixed Point

Date: 17/09/2013 – 22/09/2013

MADOCA LEX: time of convergence*

RMS (cm) / Convergence Time (min)	15	30	45	60	75	90	105	120
East	21.4	20.4	16.9	11.7	7.3	8.1	10.4	12.9
North	48.8	30.3	23.8	18.4	15.6	12.1	10.4	7.6
Up	73.7	36.6	21.0	18.2	15.2	11.7	13.5	13.3

Position RMS errors after 2 hours of convergence**

	MADOCA-LEX			IGS-RT CLK11		
	Mean	STD	RMS	Mean	STD	RMS
East (cm)	4.9	6.5	8.1	0.6	6.0	6.0
North (cm)	2.1	3.0	3.6	0.1	3.7	3.7
Up (cm)	3.7	10.9	11.5	1.6	9.9	10.1

* Averaged for 10 minutes after convergence period
** Averaged for up to 4 hours after the 2 hours

Slide 3: Real-time PPP: Static, Fixed Point

Date: 31/07/2013
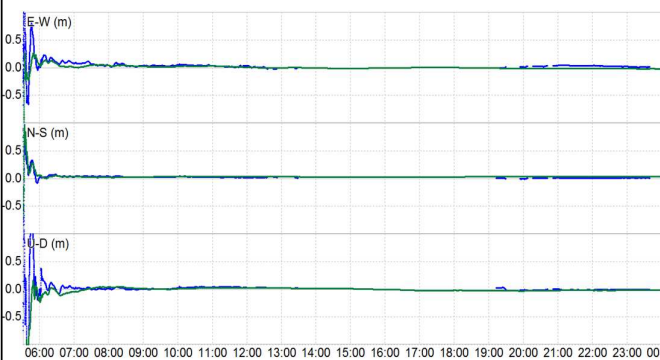
RMS(LEX) E/N/U: 2.9, 1.2, 2.6 cm   **RMS(IGS) E/N/U: 1.9, 1.5, 2.2 cm**

Slide 4

MADOCA-LEX PPP
Vehicle Test (Kinematic)

Real-time PPP: Vehicle Test

- Date: 23 October 2013
- Location: Centennial Park, Sydney, Australia
- Reference frame: ITRF2008 → GDA94
- Observations: dual-frequency, GPS only
- PPP mode: real-time kinematic
- Orbits and clocks:
  - IGS-RTS (CLK11)
  - MADOCA-LEX
- NRTK: CORSnet-NSW
- Ground truth: NRTK solutions
- Vehicle speed: ~10 km/h

Summary and Future Work

- LEX signal to support PPP applications in the QZSS coverage area.
- Accuracy of QZSS LEX PPP (Aug-Nov 2013):
  - Static: 4.1 cm (3D RMS) after 2 hours
  - Kinematic: 20 cm (3D RMS) after 90 minutes and 14.5 cm (3D RMS) after 2 hours
- JAXA is currently working on expanding MADOCA messages to incorporate multi-GNSS corrections; Multi-GNSS PPP.
- Joint research by Australian CRCSI (Cooperative Research Centre for Spatial Information) and JAXA towards PPP ambiguity resolution (PPP-AR) and PPP-RTK.

Real-time PPP: Kinematic, Vehicle
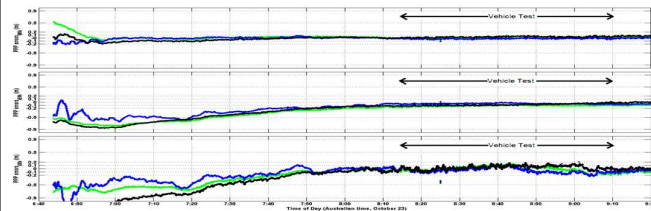
|	MADOCA-LEX		MADOCA-NTRIP		IGS-RTS	
	Mean	STD	Mean	STD	Mean	STD
East (cm)	4.7	1.6	12.0	1.8	8.2	3.2
North (cm)	2.3	1.5	0.8	1.3	3.5	1.8
Up (cm)	5.9	7.8	3.7	8.8	3.7	6.3

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- Geoscience Australia, Australia
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Terima Kasih

Thank you

Real-time PPP: Kinematic, Fixed Point

Date: 17/09/2013 – 21/09/2013
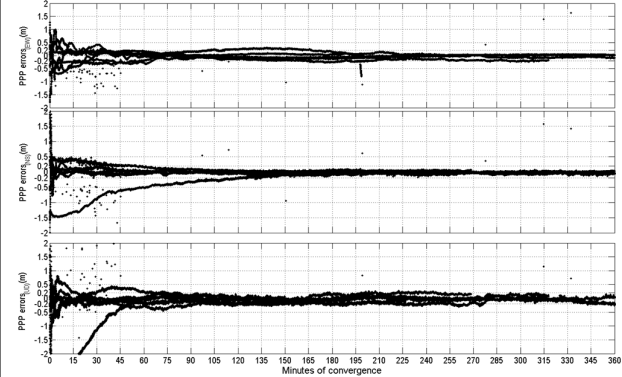
RMS(LEX) E/N/U: 8.1, 3.6, 11.5 cm   **RMS(IGS) E/N/U: 6.0, 3.7, 10.1 cm**

LEX Message Structure
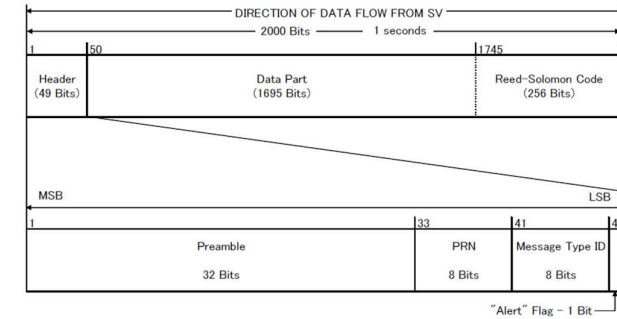
Results for Real-Time Kinematic PPP

	MADOCA QZSS		MADOCA NTRIP		IGS RTS	
	Mean	STD(1σ)	Mean	STD(1σ)	Mean	STD(1σ)
E (cm)	4.7	1.6	12.0	1.8	8.2	3.2
N (cm)	2.3	1.5	0.8	1.3	3.5	1.8
H (cm)	5.9	7.8	3.7	8.8	3.7	6.3

- Post-processed solutions (NRCAN's PPP solutions)
  - Mean E/N/H: 2.2cm / 1.6cm / 9.2cm
  - STD(1σ) E/N/H: 3.6cm / 2.7cm / 6.9cm