Transmission of Augmentation Corrections Using the Japanese Quasi-Zenith Satellite System for Real-Time Precise Point Positioning in Australia

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SUMMARY

A collaborative research project between the Australian Cooperative Research Centre for Spatial Information (CRCSI) and the Japanese Aerospace Exploration Agency (JAXA) aims to assess the feasibility of using the Japanese Quasi-Zenith Satellite System (QZSS), in particular the L-band Experimental (LEX) signal to deliver precise positioning solutions in Australia. This paper presents the results of a study to transmit precise correction messages such as satellite orbits, clocks and biases through the LEX signal to enable real-time Precise Point Positioning with Ambiguity Resolution (PPP-AR). Real-time precise correction messages based on available real-time correction products made available by the IGS were transmitted from Australia to the QZS master control station in Japan for broadcasted on the LEX signal. The correction messages were received and decoded in Australia and used to calculate real-time PPP-AR solutions. The time differences between the message time of frame and the time of arrival to the rover receiver were compared. A comparison was also made between messages transmitted on the LEX signal with a land-based communication network. The real-time PPP solutions obtained from the developed "Australian LEX" system have comparable performance to those obtained through a land-based network, demonstrating that latency and reliability of the system is adequate to support real-time PPP applications.

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1. INTRODUCTION

The Quasi-Zenith Satellite system (QZSS) is a Regional Navigation Satellite System (RNSS) in development by Japan. The development of QZSS is planned to have three phases. In the current first phase, the QZS-1 “Michibiki” launched on the 11th of September 2010 (Kishimoto et. al., 2011), is used to validate the technology, study potential applications and identify possible utilization challenges. During the second phase scheduled to start on 2018, the number of satellite will be increased to four (Kallender-Umezu,2013) At this stage the QZSS will serve as a GNSS augmentation system that covers the East Asia and Oceania Region. During the still unscheduled third phase, the number of satellites will be increased to 7 potentially allowing independent positioning.

The QZSS transmit a number of performance enhancement signals in order to fulfill its role as a GNSS augmentation system. One such signal is the LEX signal which is designed to transmit correction messages that enable position, navigation and timing applications requiring centimeter-level accuracy. LEX stands for L-band Experimental, and is a place holder name for signals that will potentially be transmitted using the L6 band (1278.75 MHz). The Centimeter-Level Accuracy System (CLAS) has been tested in Japan and demonstrated its capability of providing accuracies of a few centimeters with convergence times of less than one minute (Saito et. al, 2011).

However since these messages depend on local tropospheric and ionospheric measurements that rely on Japan’s network of Continuously Operating Reference Stations (CORS), the CLAS system will only be available in or near Japan. Complementary systems that are valid over the other parts of the region of coverage are also in development by the Japanese Aerospace Exploration Agency (JAXA). The development of these systems is based on Precise Point Positioning (PPP). Since PPP do not make use of localized measurements like atmospheric delays, receivers using PPP don’t have the need for a nearby CORS. JAXA’s system for the LEX signal have been tested in Japan achieving decimetre level positioning within a few hours (Suzuki et. al, 2014).

A joint research between the Australian Cooperative Research Centre for Spatial Information (CRCSI) and JAXA was established to test the feasibility of utilising the QZSS LEX signal to deliver high accuracy real-time precise positioning in Australia. The transmission of regional or national messages for PPP using the QZSS LEX signal is of interest for Australia as it will enable accurate positioning on parts of the country in which communication networks are either unavailable or unreliable.

The present paper describes a LEX message transmission experiment aimed at testing the feasibility of Australian generated systems for the LEX signal. In this research work, existing messages for PPP with ambiguity resolution, namely CLK9B stream from the French Government Space Agency (CNES) PPP-Wizard project was packaged in real time as LEX messages for transmission by QZS-1. The LEX messages were then transmitted from Melbourne Australia to the QZSS Master Control Station (MCS) in Japan to be broadcasted via the QZSS LEX signal. The packaged LEX messages were decoded in Australia and used for precise positioning.

This paper is structured in five sections. First, a brief description of the Japanese QZSS system and the LEX signal is given in Section 2. The LEX messages tested transmitted from Australia and the algorithms to perform ambiguity resolution in PPP are described in Section 3. The experiment settings and results of real-time PPP-AR using the transmitted messages are presented in Section 4; and finally, a summary of findings and plans for future research are outlined in Section 5.

2. QZSS AS AN GNSS AUGMENTATION SYSTEM

The QZSS is by design a RNSS that covers the East-Asia and Oceania region. In order to obtain this area of coverage, the QZSS will use a combination of Geostationary (GEO) and (Geosynchronous) Highly-inclined Orbits (HEO). The QZSS HEO is designed in a way that satellites placed in such an orbit will stay near the zenith on Japan for at least 8 hours a day. The blue lines in Figure 1 show the ground track for the HEO satellites. Currently the QZSS consist of one satellite, the QZS-1 "Michibiki" placed in this HEO orbit. By the end of 2018, 2 HEO satellites and a GEO satellite will join the QZS-1, allowing the QZSS to operate as a GNN augmentation system.

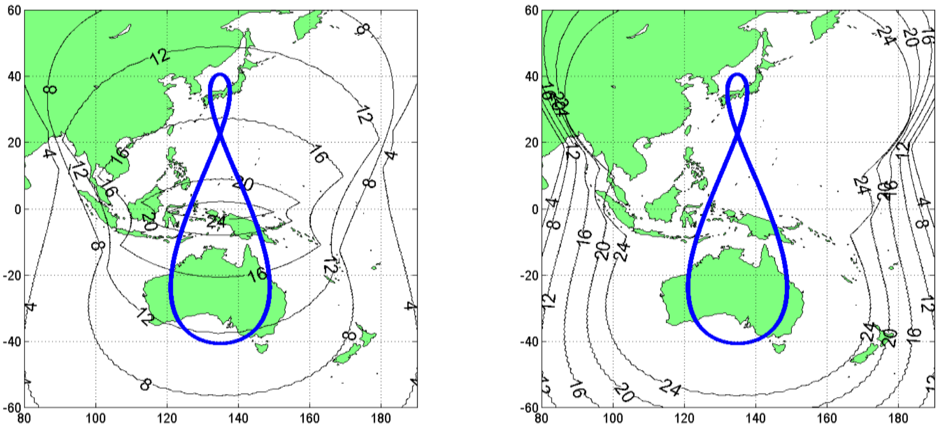

Figure 1. Coverage area of QZSS. Left: Number of hours a day QZS-1 satellite is above 40° of elevation. Right: Number of hours a day at least one satellite will be above 40° of elevation once the four satellites constellations are active in 2018.

2.1 The QZSS LEX signal

As a GNSS augmentation system, the QZSS aims to provide availability and performance enhancement to GNSS systems in the region of coverage. Availability enhancement is achieved by transmitting signals that are compatible with GPS satellites, i.e. L1 C/A, L2C, L5 and L1C signals, effectively increasing the number of GPS satellites available in the region. Performance enhancement is achieved by transmitting two additional messaging signals, i.e. L1 Sub-meter class Accuracy with Integrity Function (L1-SAIF) and the LEX signal (JAXA, 2014).

The LEX signal is an augmentation signal transmitted using the 1278.75 MHz (L6) carrier and is designed to correction messages GNSS signals in order to enable high accuracy positioning. . The key advantage of the LEX signal is the relatively large data capacity. Table 1 shows the data rates for the GNSS navigation messages transmitted using different signals. The LEX signal, with its 2000 bps capacity is capable of transmitting eight times the information of traditional satellite based augmentation signals (SBAS).

Message	Constellation	Carrier (MHz)	Data Rate (bps)
NAV	GPS	1575.42	50
SBAS	WAAS/MSAS/EGNOS	1575.42	250
C/NAV	Galileo	1278.75	500
LEX	QZSS	1278.75	2000

Table 1. Data transmission rate of the different navigation messages.

In exchange for this higher data rate, the LEX signal tends to require better conditions for reception than other ranging signals. However 40 degrees of elevation is enough to ensure reliable demodulation and decoding, even with a standard patch antenna (Harima et. al., 2014). The left pot in Figure 1 shows the number of hours a day the QZS-1 satellite can be seen at more than 40º of elevation over the East-Asia and Oceania region. The right plot in Figure 3 show the estimated number of hours a day, at least one QZSS satellite will be over 40º of elevation. The LEX signal can be expected to be available 24-hours a day for most of the East-Asia and Oceania with three active HEO satellites.

2.2 PPP using the LEX signal

Several types of correction messages are being tested to provide high accuracy positioning using the LEX signal. The CLAS messages for example, are generated from measurements from a dense CORS network to achieve positioning performances similar to those obtained using network RTK solutions (Saito et al 2011). However, as mentioned before the CLAS in its current state is only usable by users in Japan. Although messages based on networks from other countries may also be included in the future, system requiring a dense CORS network is not suitable to take advantage of the QZSS large coverage area.

For this reason alternative GNSS augmentation messages based on PPP are being developed for the LEX signal. Traditional PPP uses an iono-free linear combination of measurements from two different carrier frequencies to eliminate the effects of the Ionospheric delay which is the largest error with local variability:

$$P_{if} = \frac{f_1^2}{f_1^2-f_2^2}P_1 - \frac{f_2^2}{f_1^2-f_2^2}P_2$$
$$\varphi_{if} = \frac{f_1^2}{f_1^2-f_2^2}\varphi_1 - \frac{f_2^2}{f_1^2-f_2^2}\varphi_2 \qquad (1)$$

where f_i is the frequency of the L_i band carrier and P_i and φ_i being the pseudorange and carrier phase measurement for the signal on the L_i band.

$$P_i = \rho + dt + m_tT + \frac{f_1^2}{f_i^2}I + B_{P_i}$$
$$\varphi_i = \rho + dt + m_tT - \frac{f_1^2}{f_i^2}I + \frac{c}{f_i}N_2 + B_{L_i} \qquad (2)$$

here ρ is the estimated satellite-receiver distance, dt is the satellite clock error, T and m_t are the tropospheric delay and its mapping function, c is the speed of light, N_i is the phase ambiguity, and B_{Pi} and B_{Li} correspond to the hardware biases for the pseudorange and carrier phase measurements. Index for satellite are omitted for simplicity.

Since the Ionospheric delay can be considered to be inversely proportional to the square of the carrier frequency they are eliminated by forming the linear combination in (1). Leaving only Tropospheric delays, satellite biases, satellite orbit errors and satellite clock errors as sources of errors.

$$P_{if} = \rho + dt + m_tT + \frac{f_1^2}{f_1^2-f_i^2}B_{P_1} - \frac{f_2^2}{f_1^2-f_2^2}B_{P_2}$$
$$\varphi_{if} = \rho + dt + m_tT + \frac{cf_1}{f_1^2-f_2^2}N_1 - \frac{cf_2}{f_1^2-f_2^2}N_2 + \frac{f_1^2}{f_1^2-f_i^2}B_{L_1} - \frac{f_2^2}{f_1^2-f_2^2}B_{L_2} \qquad (3)$$

The tropospheric errors can be estimated with centimetre level accuracy based on the tropospheric zenith delay, and the other tree sources of error are global in nature, thus they can be measured used a sparse network of global CORS.

The LEX messages in development by JAXA are generated using the Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis (MADOCA) software. The MADOCA software the computes precise satellite orbits and clock corrections required for PPP. These messages are then encoded into MADOCA-LEX (Harima et. al. 2014) messages as shown on Figure 2.

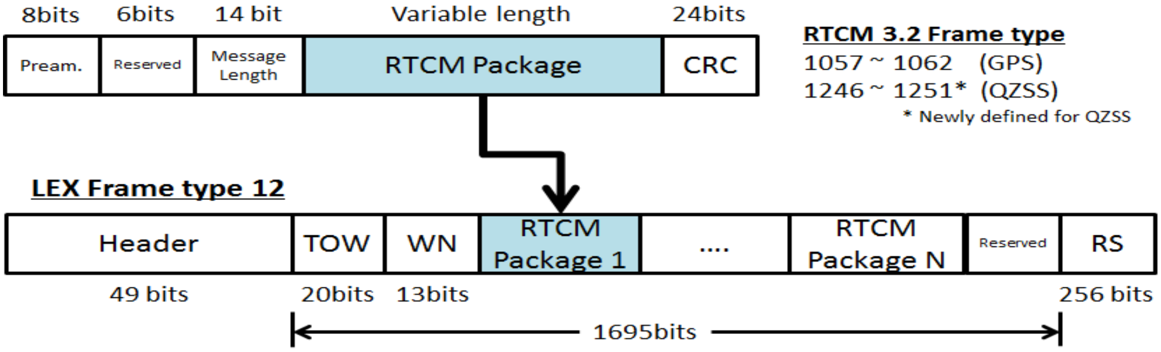

Figure 2. Packaging of RTCM messages on QZSS LEX signal. 1695 bit data part of MADOCA-LEX messages are includes the GPS time of transmission and the data part of RTVM messages.

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The MADOCA software outputs State Space Representation (SSR) messages for satellite orbits and clocks that follow the Radio Technical Commission for Maritime Services (RTCM) protocol (RTCM, 2013). The LEX message header, GPS time of transmission and Reed-Solomon parity symbols are added to the data part of the RTCM messages to complete the LEX frame message.

Real time evaluation PPP using corrections from MADOCA-LEX messages have been performed as part of the joint research project between the Australian CRCSI and JAXA. The positioning accuracy was 8.8 cm of horizontal RMS and 14.5cm of 3-dimentional RMS using these products.

3. PROTOTYPE LEX MESSAGES FOR PPP WITH AMBIGUITY RESOLUTION

As a benchmark for a system using the QZSS LEX signal to enable high accuracy positioning in Australia, an experiment was performed in which LEX messages generated in Australia were sent to the QZSS MCS to be broadcasted by the QZS-1 satellite. Moreover, in order to test the full capabilities of the system, correction messages that include the satellite phase biases B_{Li}, which will enable PPP with Ambiguity Resolution (PPP-AR).

3.1 Ambiguity resolution strategies for PPP

Ambiguity resolution takes advantage of the fact that the phase ambiguities N_i are integer valued. By solving and fixing the values of N_i to integer values error associated with these parameters can be eliminated, this combined with the transmission of precise values for satellite orbits, clocks and biases. Allows the use of carrier phase measurements to calculate the receiver position with centimeter-level accuracy.

Several strategies have been proposed for PPP-AR, each associated with specific types of corrections to be transmitted to the end-user. As an example the method proposed by Laurichesse (Laurichesse et. al., 2009) from French Space Agency CNES, solves the equations in (2) directly estimating T and I as variables. In order to achieve this, the messages for the CNES method include B_{Pi} and B_{Li} for the GPS L1 and L2 signals. This algorithm attempts to take full advantage of the code and phase biases for individual signals by resolving the un-combined and un-differenced ambiguities.

On the other hand, other PPP-AR strategies like those prosed by Ge. (Ge et. al, 2007) limits itself to resolving the ambiguity of a single differenced, ionosphere-free combination like those in equation (3). For this case, the code biases are unnecessary as they can be added to the satellite clock. As for the phase biases the iono-free combination of the biases is necessary to compensate the effects on the carrier phase measurements

$$B_{IF} = \frac{f_1^2}{f_1^2-f_i^2}(B_{L1} - B_{P1}) - \frac{f_2^2}{f_1^2-f_2^2}(B_{L2} - B_{P2}) \qquad (4)$$

The pseudorange biases are included in (4) as a reminder that the clock correction to be transmitted correspond to the iono-free combination.

Because the iono-free combination destroys the integer characteristic of the phase ambiguities, Ge's method uses the Melbourne-Wubenna combination to restore the integer nature of ambiguities, the corresponding bias combination also need to be transmitted.

$$MW = \frac{f_1}{f_1-f_2}\varphi_1 - \frac{f_2}{f_1-f_2}\varphi_2 - \frac{f_1}{f_1+f_2}P_1 - \frac{f_2}{f_1+f_2}P_2 = \frac{c}{f_1-f_2}[N_1 - N_2] + B_{MW}$$

$$B_{MW} = \frac{f_1}{f_1-f_2}B_{L1} - \frac{f_2}{f_1-f_2}B_{L2} - \frac{f_1}{f_1+f_2}B_{P1} - \frac{f_2}{f_1+f_2}B_{P2} \qquad (4)$$

The corrected Melbourne-Wubenna combination can then be used to resolve the difference between the L1 and L2 ambiguities. Once the difference is resolved, N1 (and subsequently N2) can be resolved using the phase carrier measurements.

$$P_{if} = \rho + dt_{if} + m_t T$$

$$\varphi_{if} = \rho + dt_{if} + m_t T + \frac{c}{f_1+f_2}N_1 - \frac{cf_2}{f_1^2-f_2^2}(N_1 - N_2) + B_{NL} \qquad (5)$$

Once the values of N_1 an N_2 are resolved, the difference between the integer and float ambiguity are used to adjust the positioning solution.

Ge's method come as a natural extention of the standard PPP solution, and the comparation of the its performance with the standard PPP solution is more strait forward. For this reason although the messages were based on the realtime corrections from CNES, Ge's Method was used to perform PPP-AR.

3.2 Prototype messages for PPPAR

To the extent of our knowledge, the CNES CLK9B stream is the only publicly available real-time stream enabling PPP-AR. So the messages from the CLK9B stream were adapted for Ge’s algorithm. The CNES CLK9B real-time stream consist of satellite orbit and clocks correction messages (RTCM type 1060 and 1066), and satellite bias messages (RTCM type 1065 and a modified version of RTCM type 1059) as outlined in Table 2. Since the CNES messages do not contain the phase biases necessary to perform PPP-AR using GLONASS satellites, the experiment this time will again be limited to GPS satellites.

RTCM type	Contents	UDI
1059	Biases for GPS	5 sec
1060	Orb. And Clk. for GPS	5 sec
1065	Biases for GLONASS	5 sec
1066	Orb. & Clk. for GLONASS	5 sec

Table 2. Contents of CNES CLK9B real-time stream. Message type 1059 in this stream have been modified to support phase biases as well as pseudorange biases.

In order to enable PPP-AR using Ge’s method, the biases contained in the stream CLK9B were transformed to ionosphere-free Melbourne-Wubenna combination biases. The biases were codified in a modified message type 1059. Also, in order to reduce the data rate, the clock and orbit corrections in message 1060 were re-encoded in messages type1057 and 1062. The content of the LEX messages for PPP-AR used in this research is shown in Table 3.

Type	UDI	Data	Description
1057	5 sec	O_R	Orbit offset (Radial)
		O_A	Orbit offset (Along-track)
		O_C	Orbit offset (Cross-track)
1062	5 sec	dt^S	Clock Correction
1059	5 sec	B_{MW} *(ID:24)*	MW combination bias
		B_{IF} *(ID:25)*	Ionosphere-free combination bias

Table 3. Contents of the LEX messages for PPP-AR. The bias ID for B_{WL} and B_{NL} were arbitrary assigned and are not part of the standard message 1059.

It is necessary to emphasize that the messages from the CLK9B stream were meant to be used to attempt ambiguity resolution for un-combined and un-differenced measurements. It is a possibility that packaging the correction messages as described in the present paper limits the potential of the CLK9B corrections.

3.3 PPPAR with CNES streams

Post-processed PPPAR solutions were calculated in order to verify the effectiveness of the CNES corrections, in particular when used with Ge's method. Messages from the CLK9B stream were recorded from 12th to 18th of August 2014 and 12th to 18th September 2014. LEX messages were generated based on these corrections and used for PPPAR using Ge's algorithm. Figure 3 shows the horizontal RMS position errors with respect to the known positions of the sites.

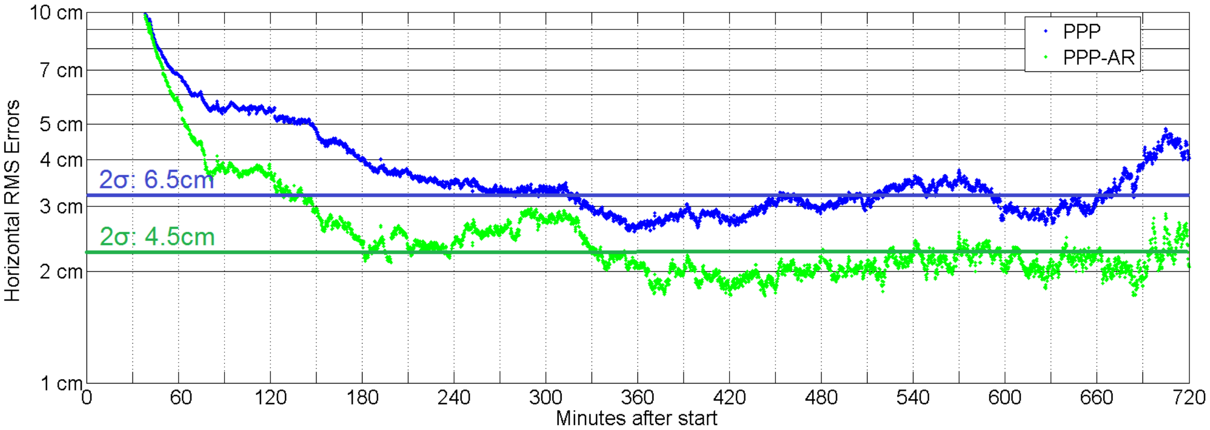

Figure 3. Horizontal positioning accuracies for standard PPP and PPP-AR (Post processing)

A total of 140 solutions were calculated using the above corrections and GPS observations from 10 stations around Australia: Alice Springs (ALIC), Ceduna(CEDU), Darwin(DARW), Hobart(HOB2), Karratha(KARR), Melbourne(MOBS), Perth(HIL1), Tibooburra(TBOB), Toowoomba(TOOW) and Townsville(TOW2).

As it can be seen from the figure there is a gain of 30% in the accuracy on the converged solution product of the ambiguity resolution. The 2σ RMS horizontal errors are 6.5 cm for the standard PPP solution and 4.5 cm for the PPPAR solution. The difference is much less significant on the vertical component, with the PPPAR solution having 13.1cm of accuracy to the 13.2cm of standard PPP.

Figure 4 shows the time to first fix for the calculated positioning solutions. For most cases the PPP solutions take between 30 minutes to one hour to achieve convergence.

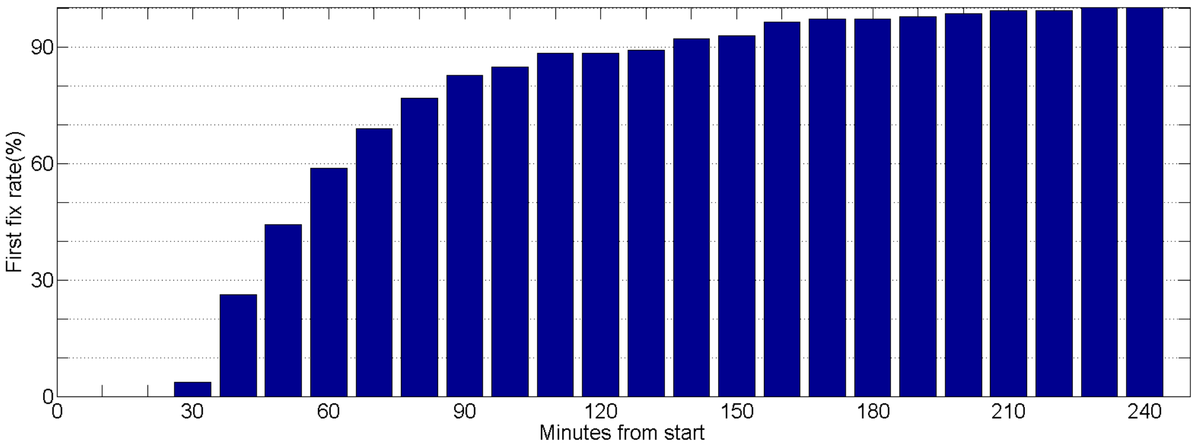

Figure 4. Time to first fix for Post- processed PPPAR solutions using modified CNES corrections

However, for about 5% of the cases it took more than 3 hours for the PPPAR algorithm to converge to a fixed solution. The reason for these long times for convergences are likely due to the fact that, for the implementation on the present research, the algorithm only calculates the fixed state solution when it can solve the ambiguities for all satellites above 10 degrees of elevation. This comes with the consequence that if the corrections or observation for a single satellite have large errors, the solution cannot be fixed until the satellite disappear from the field of vision, or until the errors are corrected. A PPPAR algorithm capable of partial ambiguity resolution should help attain faster convergence times.

4. TRANSMISSION OF MESSAGES FOR PPP-AR USING QZS-1

In the experiment described in the present paper, the LEX messages described in previous sections were generated generated in RMIT University in Melbourne and transmitted via internet to the QZSS master control station. The transmitted messages were then broadcasted by the QZSS satellites LEX signal.

The broadcasted LEX messages were used to compute ambiguity resolved PPP solutions using Ge’s method. The test site used for the real-time poaitioning tests was GNSS reference station in Bundoora, Victoria approximately 16Km north of Melbourne. The GNSS receiver, i.e. a Javad DELTA-G3T was connected to the Javad GrAnt-G3T antenna shown in Figure 5. Both the GNSS receiver and the LEX receiver were established at the RMIT Bundoora tracking station. The approximate coordinates of the location are 37˚40’51’S of latitude and 145˚03’52’E longitude.

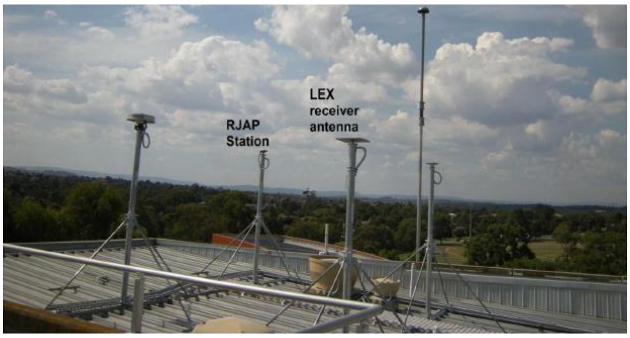

Figure 5. Antennas used for real-time PPP-AR experiments. The LEX signal was received using a standard patch antenna connected to a software receiver. The GNSS signals were tracked using a Javad GNSS receiver (RJAP station).

All positioning solutions were generated using the RTKLIB software [13] and were GPS-only solutions. For standard PPP, the positioning algorithms in RTKLIB were used without modification. Small modifications were made for the PPP-AR tests. Although the measured position was fixed, the solutions were calculated without making such an assumption, thus it can be expected that similar results can be obtained in a kinematic processing using data collected in open sky conditions.

The real time transmission experiments described in thepresent pared were performed on between the 8th and 10th of June 2014 and between the 27th of September and 1st of October 2014.

It was found in previous investigations that the satellite elevation angle required to reliably demodulate and decode the LEX messages was 40˚ using a patch antenna. Thus the PPP and PPP-AR solution presented in this paper were calculated during times at which the elevation of the QZS-1 satellite was above 40˚.

4.1 Message outages and latency

For the tests performed on June 2014, status of the LEX transmission was monitored. The LEX message outage rates and the added latency was measured during the 3 days of transmission.

The LEX message outages were determined by comparing the RTCM messages received at the LEX message generator and the RTCM message received at Bundoora. Outages for clock messages were 0.49% and 0.47% for orbit messages when the QZS-1 satellite was above 40 degrees of elevation. Since the bias messages were given a very low priority with respect to clock and orbit messages, 34.5% of the bias messages were discarded during the generation of the LEX messages. However, the time between consecutive bias messages was above 1 minute in only 2 instances for the period in which the QZS-1 was above 40˚.

The added latency due to the LEX message generation and transmission for the period of 8 to 10 of June is shown on Figure 6. The added latency was determined by measuring the time difference between the time of arrival of the RTCM message to the LEX message generator in Melbourne and the time of arrival of the LEX message to the LEX receiver shown on Figure 5

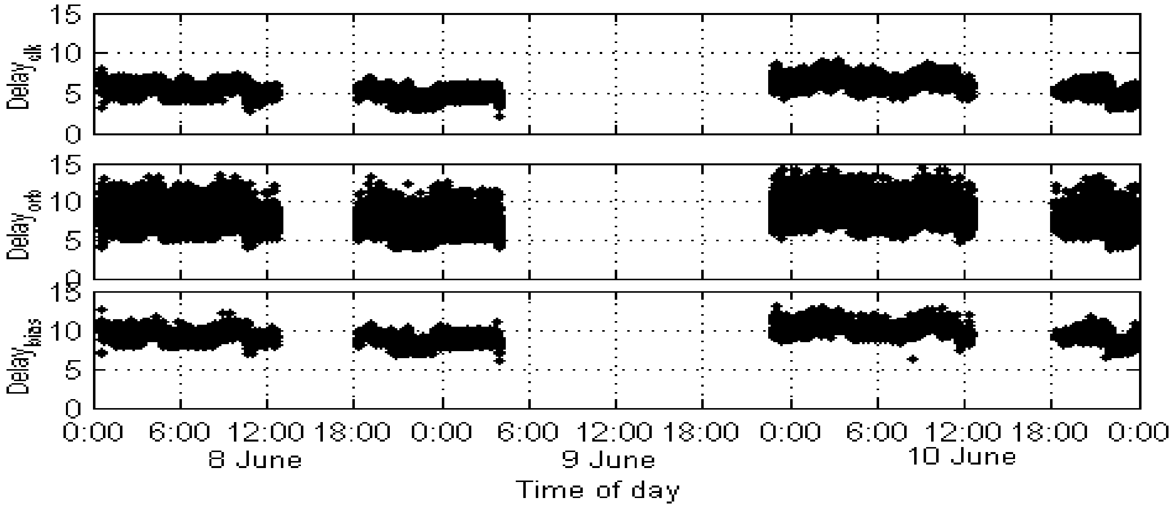

Figure 6. LEX message latency for clock, orbit and bias messages Clock messages are sent first, followed by orbit messages and then bias messages. Average latencies were 5.67 sec. for clock 7.90 second for orbit and 9.45 seconds for bias messages.

The average latency added due to the LEX message encoding scheduling and transmission was 5.67 seconds for the clock messages, 7.90 seconds for the orbit messages 9.45 seconds for the bias messages.

4.2 Performance of real-time PPP-AR using LEX messages

The LEX messages for PPPAR were evaluated by calculating real-time positioning solutions at the Bundoora station. In the present section we describe the solutions obtained in tests performed on June and September 2014.

Figure 7 shows the time series for the PPP-AR solutions calculated on the 8th of June 2014. Two solutions were calculated each day using the same GNSS observations. For one of the solutions the LEX messages described above were sent to the QZSS MCS and uploaded to the QZS-1 for broadcasting. In the second method, the RTCM messages where obtained directly from the CNES NTRIP caster. In figure 7 the dark colored solutions correspond to the solutions obtained using messages from the NTRIP caster, and the light colored solutions correspond to solutions obtained using the QZSS LEX signal as a mediun to broadcast the corrections.

As it can be seen in figure 7, the solutions are very similar to each other. This means that the latency and outages added by the LEX message transmission process has little influence on the solutions. For the time to first fix the difference between solutions was below 3.7%.

finally the RMS of the difference between ambiguity resolved solutions was less than 1 cm for all tests.

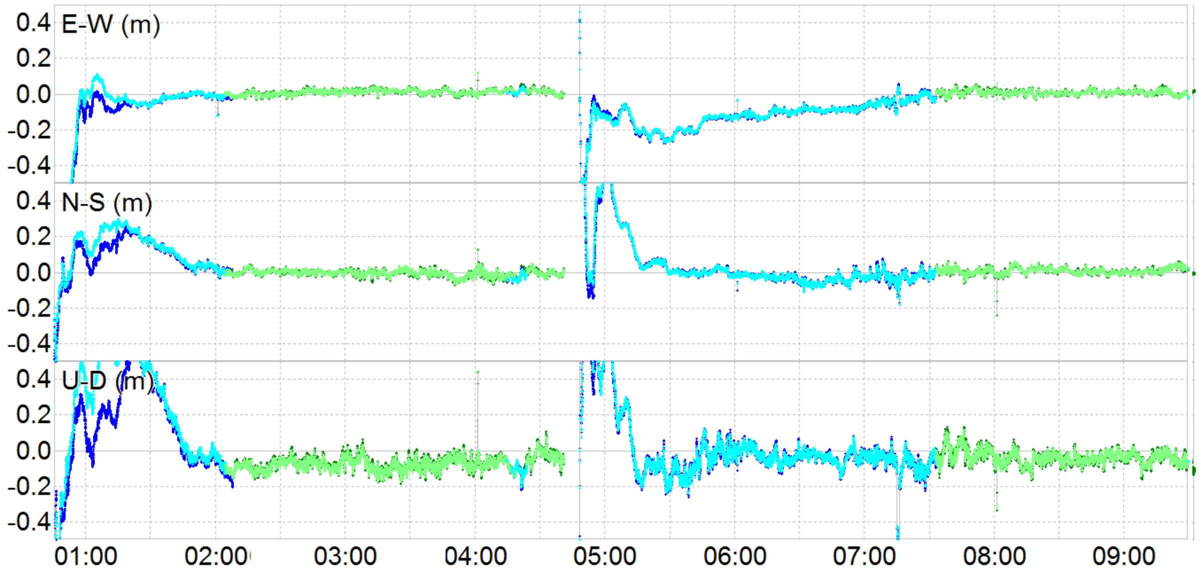

Figure 7 Sample solution of real-time PPPAR. Blue and dark green: ambiguity float and ambiguity fixed positions obtained using corrections from NTRIP caster. Cyan and light green: using corrections from LEX signal

Table 4 and table 5 show the positioning performance of the PPPAR algorithm on the June and September tests respectively.

Start day	Solution time	TTFF	Horiz. RMS (2σ)	Vert. RMS (2σ)
8th June of 2014	00:30 to 09:15 UTC	01:32:26	5.0 cm	12.8 cm
8th June of 2014	22:00 to 04:00 UTC	03:11:58	4.6 cm	14.6 cm
9th June of 2014	23:00 to 04:45 UTC	02:18:02	5.4 cm	9.8 cm
10th June of 2014	04:50 to 10:00 UTC	02:22:47	6.2 cm	12.2 cm

Table 4. Results for PPP-AR perfromed on June 2014, time to first fix, and horizontal and vertical accuracy of ambiguity resolved solutions.

Start day	Solution time	TTFF	Horiz. RMS (2σ)	Vert. RMS (2σ)
27th Sept. of 2014	17:00 to 21:00 UTC	01:46:54	4.6 cm	7.0 cm
28th Sept. of 2014	18:30 to 21:30 UTC	01:17:53	4.3 cm	10.0 cm
29th Sept. of 2014	15:30 to 23:30 UTC	01:38:24	5.8 cm	12.3 cm
30th Sept. of 2014	18:00 to 23:00 UTC	01:59:03	3.5 cm	12.3 cm
1st Oct. of 2014	17:30 to 23:30 UTC	02:00:53	4.2 cm	10.3 cm

Table 5. Results for PPP-AR perfromed on Sept-Otc. 2014, time to first fix, and horizontal and vertical accuracy of ambiguity resolved solutions.

TTFF varies from about 80 minutes for the test on September 28 to above 3 hour for the test starting at 22:00 on the 8th of June. The 2 σ RMS errors of the fixed solutions range from 3.5 cm to 6.2 cm for the horizontal component and below 7.0 cm to 14.5 cm for the vertical

component. The average value for the horizontal RMS accuracy was 4.9cm, although this is about 10% higher than the post-processing result, it can be easily explained by the use of different receiver and the small sample of real-time solutions.
The time for fixing on the other handseems to be larger than expected with most of the solutions taking between one and two hours to achieve, convergence. This is significantly longer than what it can be expected from the post processed results, however, since solutions obtained using the CNES messages directly havesimilat convergence times, the source of these long convergence times are not on the LEX transmission process.

5. CONCLUSION

A joint project between the Australian CRCSI and JAXA aims to assess the feasibility of using the LEX signal to potentially deliver a precise positioning service in Australia. The capabilities of the QZSS LEX signal to deliver standard-PPP service with decimeter-level accuracy through the transmission of MADOCA-LEX type messages has been demonstrated in Japan and Australia. The next logical step is to test ambiguity resolved PPP, as it can offer a 30% improvement in accuracy over standard PPP.

This paper has described a preliminary test for the transmission of a prototype “Australian-generated LEX corrections” aiming to demonstrate the capability to deliver ambiguity resolved PPP using the LEX signal. Prototype LEX messages, based on CNES real-time products were transmitted from Australia to the QZS MCS in Japan and broadcasted via the LEX signal.
Real-time PPP-AR solutions with horizontal accuracies of about 4.9 cm (2σ RMS) and vertical accuracies of 11.6 cm (2σ RMS) was demonstrated on experiments performed in June and September 2014. Thi result is only 10% higher than post-processed results. The main remaining issue is the convergence which times ranges from 1 hour to more than 3 hours in one case.

However comparation with solutions obtained using the CNES messages directly indicates that the LEX message transmission process has little effect on both the accuracy and convergence of the PPPAR solutions. The transmission added an average of 5.67 seconds of latenc, and the message outage rate was below 0.8%. The overall effect of the outages and added latencies on the PPP solutions was found to be between less than 1 cm of RMS horizontal positioning difference and less than 3.7% in convergence times.

Future efforts aiming to further enhance the capabilities of the LEX signal for high accuracy in Australia include the addition of Regional or National Ionospheric measurements into the LEX messages to help accelerate convergence. Further rea-time tests with improved messages and algorithms are planned for May 2015.

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