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Feasibility Study on Integration of SSR Correction into Network RTK to Provide More Robust Service

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ABSTRACT

Network RTK is a highly practical technology that can provide high positioning accuracy at levels between cm~dm regardless of user location in the network by extending the available range of RTK using reference station network. In particular, unlike other carrier-based positioning techniques such as PPP, users are able to acquire high-accuracy positions within a short initialization time of a few or tens of seconds, which increases its value as a future navigation system. However, corrections must be continuously received to maintain a high level of positioning accuracy, and when a time delay of more than 30 seconds occurs, the accuracy may be reduced to the code-based positioning level of meters. In case of SSR, which is currently in the process of standardization for PPP service, the corrections by each error source are transmitted in different transmission intervals, and the rate of change of each correction is transmitted together to compensate the time delay. Using these features of SSR correction is expected to reduce the performance degradation even if users do not receive the network RTK corrections for more than 30 seconds. In this paper, the simulation data were generated from 5 domestic reference stations in Gunwi, Yeongdoek, Daegu, Gimcheon, and Yecheon, and the network RTK and SSR corrections were generated for the corresponding data and applied to the simulation data from Cheongsong reference station, assumed as the user. As a result of the experiment assuming 30 seconds of missing data, the positioning performance compensating for time delay by SSR was analyzed to be horizontal RMS (about 5 cm) and vertical RMS (about 8 cm), and the 95% error was 8.7 cm horizontal and 1cm vertical. This is a significant amount when compared to the horizontal and vertical RMS of 0.3 cm and 0.6 cm, respectively, for Network RTK without time delay for the same data, but is considerably smaller compared to the 0.5 ~ 1 m accuracy level of DGPS or SBAS. Therefore, maintaining Network RTK mode using SSR rather than switching to code-based DGPS or SBAS mode due to failure to receive the network RTK corrections for 30 seconds is considered to be favorable in terms of maintaining position accuracy and recovering performance by quickly resolving the integer ambiguity when the communication channel is recovered.

Keywords: GNSS, network RTK, SSR, operation time, service coverage

1. INTRODUCTION

The errors in GPS Standard Point Positioning (SPP) user positions can be mainly divided into GPS system errors, signal path errors, and user related errors. The GPS system errors are an error in the satellite itself, such as satellite orbit and clock errors. The signal path errors are an error caused by the change of the path from GPS satellites to users due to the influence of the Earth's atmosphere, which includes ionospheric and tropospheric delay errors. Finally, the user related errors are an error that occurs depending on the

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user's receiving environment, such as multipath error and receiver noise (Misra & Enge 2006).

Methods of differentiating the measurements of reference stations and users such as Differential GPS (DGPS) and Real Time Kinematics (RTK) have been mainly used to remove the errors included in GPS signals and improve the positioning performance. These differential augmentation systems remove errors based on the high spatial and temporal correlation between GPS signal errors, and is an effective method when users located at a short distance from the reference station apply recent corrections with little time delay. While DGPS using code measurements allows the correction age of 5 to 10 seconds in the range of about 100 ~ 150 km from the reference station, RTK using carrier phase measurements needs to receive corrections every second within a range of about 10 ~ 15 km. If corrections are not received for a long period of time, such as 30 seconds, the resolved ambiguity cannot be maintained and the positioning mode is changed from fixed to float mode, resulting in a degradation to code-based accuracy.

A technique that models the Spatial Decorrelation Error based on a network between reference stations has been developed to efficiently expand the service coverage, and the Wide Area Differential GPS (WADGPS) (Kee et al. 1990) is widely used for code-based positioning and the Network RTK is used for carrier phase-based positioning. In case of WADGPS, in order to reduce the influence of temporal decorrelation error, the method to transmit correction messages for error sources such as satellite orbit and clock errors, ionospheric delay at different intervals and generate range correction by combining parameters distributed across multiple messages is defined as the standard of Satellite Based Augmentation System (SBAS) (RTCA 2006). In case of Network RTK, the Compact Network RTK method that integrates Compact RTK (Kee & Kim 2002) method with Network RTK to effectively reduce temporal decorrelation error of the carrier phase correction has been proposed (Park 2008) and applied for research on GNSS infrastructure for autonomous vehicles.

Recently, there is a growing interest in State Space Representative (SSR) method, which provides carrier phase correction by each error source and standardization is actively in progress as well (Kee et al. 2013). The SSR message was originally proposed for Precise Point Positioning (PPP), which was theoretically intended to be used to transmit carrier phase corrections for global coverage by each error source at different intervals. The characteristics of SSR message are expected to complement the performance of Network RTK under adverse conditions of transmitting corrections, so the purpose of this study is to confirm the possibility through simulation.

2. FEATURES OF NETWORK RTK

In order to compensate for the weakness of carrier phase positioning that the accuracy decreases as distance from the reference station increases, Network RTK extends the available range of RTK by configuring the reference station network so that users in the service area can maintain uniform performance regardless of their location. The Network RTK infrastructure performs carrier phase ambiguity resolution through double difference of measurements between reference stations, and then transmits the network RTK correction used to reduce the spatial decorrelation error of satellite errors to the user. The Network RTK can be divided into Virtual Reference Station (VRS), Flächen Korrektur Parameter (FKP), Master-Auxiliary Concept (MAC), Pseudo-Reference Station (PRS), and individualized Master Auxiliary corrections (i-MAX) according to the implementation method, and the type of correction used for each method is also different (Takac & Zelzer 2008).

VRS is a method that generates and transmits virtual carrier phase observation data by modeling data from 3 reference stations near the user, thereby acquiring the effect of having a reference station at user's location. The form and application of correction are identical to the conventional single reference station RTK, so the configuration is simple and the performance is the highest in terms of accuracy. However, since VRS correction is calculated according to user's location, there are limitations in the number of simultaneous users and privacy problems, and is somewhat unsuitable for the navigation of vehicles because the performance degrades as vehicles move farther away from the initial position.

The Network RTK methods that use one-way communication without exposing user's location are FKP and MAC, and both methods separate GPS error sources into dispersive terms and non-dispersive terms and transmit them to the user. However, FKP assumes a flat distribution of errors for each satellite according to latitude and longitude, and provides the user with gradient information of the modeled error plane so that the user can compensate the spatial decorrelation error on the plane. MAC uses measurements or corrections as they are just like the conventional RTCM message, but reduces data size by using the difference between the Master and Auxiliary reference station, so that the user can directly model error by using corrections to compensate the spatial decorrelation error. Although there may be some difference in the performance between FKP and

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MAC depending on whether modeling is performed in the infrastructure or by the user, theoretically they are equivalent concepts.

Based on such one-way communication, Network RTK provides highly accurate corrections at levels between cm~dm to unlimited users located in the reference station network as well as is applicable to moving objects in wide areas such as autonomous vehicles, which makes it an infrastructure suitable for future high-performance navigation. In particular, main advantage for users using dual-frequency receivers is that they can acquire an accuracy of decimeters with only a few or tens of seconds of latency under good satellite visibility conditions.

The observation data used as RTK correction is very sensitive to time delay because it includes high-dynamic terms such as distance between the receiver and satellite. Thus, for unidirectional network RTK services, corrections need to be transmitted at least every second using a data link of approximately 2400 ~ 4800 bps in a service area of 70 km radius, and requires a very large bandwidth compared to the 100 ~ 200 bps bandwidth of DGNSS using code measurements and the 250 bps bandwidth of SBAS (Park et al. 2010). When applying Compact Network RTK method, the bandwidth can be reduced to approximately 700 bps or less, and can easily avoid significant performance degradation even with a time delay of about 5 to 7 seconds, so that unidirectional Network RTK can be easily implemented even in the regions with poor data reception (Park & Kee 2010). However, under the domestic expressway environment, there are many sections where internet connection is lost as shown in Fig. 1, and in some section the connection does not automatically recover after about 30 seconds (Kim et al. 2013). Therefore, in order to provide stable and accurate positioning navigation service, back-up positioning method that do not significantly degrade the positioning accuracy are required in such poor communication areas, and SSR messages, which were intended to be used as correction for PPP, are likely to be used as an alternative.

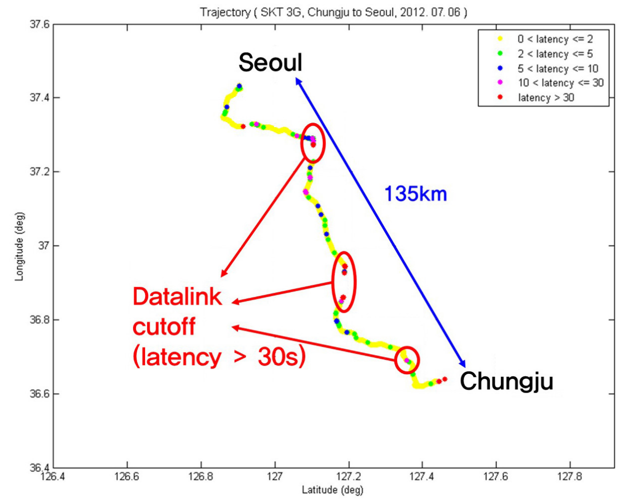

Fig. 1. Test result of latency error analysis (upper: spatial variation of time delay, below: temporal variation of position error) (Kim 2013).

3. RTCM SSR CORRECTION

Unlike SPP, PPP is a positioning technique that improves accuracy by applying precise satellite orbit and clock error, and atmospheric and crustal movement correction models (Lee 2013), and even though the theory has been established through static PPP research (Zumberge et al. 1997), it has been mainly used for static post-processing due to limitations on the number of visible satellites and performance issues of satellite orbit estimates. Since then, kinematic PPP technique has been proposed (Kouba et al. 2001) and it has been applied in various fields including glacier flow velocity and crustal displacement according to the increase in the constellation such as GLONASS and Beidou in addition to GPS and improved precise orbit and clock estimation performance. In particular, as the performance of precise orbit and clock provided by international organizations with global reference stations such as International GNSS Service (IGS) has improved significantly, the research and application related to PPP have become active and diverse.

Although PPP is a very efficient positioning technique depending on its application, the convergence time takes about 30 to 60 minutes and the difficulties in real-time ambiguity resolution make it difficult to apply in real-time applications compared to conventional RTK. In order to compensate for this issue, PPP-RTK technique integrating PPP and Network RTK has been proposed. It is similar to PPP in that the master station calculates and transmits the satellite orbit and clock corrections to user, but the ionospheric and tropospheric errors are provided based on the observation data from the reference station network in order to shorten the initial convergence time. The correction provided by PPP-RTK is called SSR and it includes satellite orbit and clock errors, satellite bias, tropospheric error, and ionospheric error.

The SSR distinguishes the types of correction according to the characteristics of the error and provides the modeled parameters. Since the parameters are modeled by each error source, transmission interval is set by considering the rate of change of each error source. The transmission interval of the rapidly changing satellite clock correction is short as 1 to 10 seconds and transmission interval of the slowly varying

Table 1. Standardization status of SSR message.

SSR correction	Update rate (s)	Parameters	Standardization
SV orbit	60	radial / along-track / cross-track correction	MT1057
SV clock	10	C0, C1, C2	MT1058
SV HR clock	1		MT1062
Ionospheric delay	30	Grid Point (lat/lon), STEC	On-going
Tropospheric delay	30	Grid Point (lat/lon), ZTD, ZWD	On-going

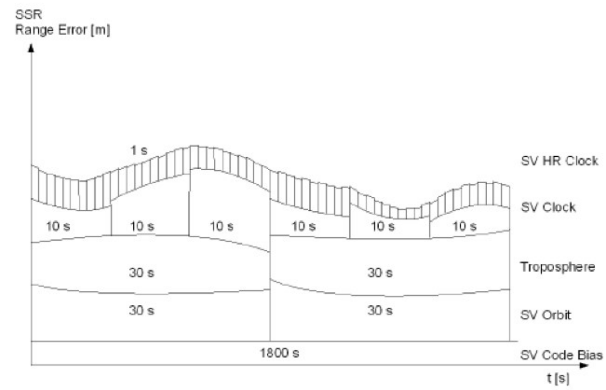

Fig. 2. Example of SSR message broadcast (RTCM 2016).

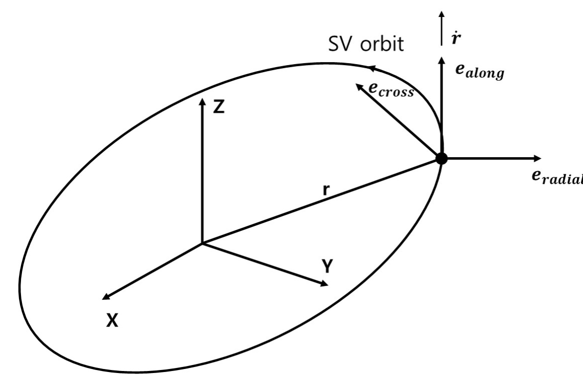

Fig. 3. Satellite obit correction (RTCM 2016).

satellite bias is 30 minutes. Among RTK standards discussed in the RTCM standards committee, some of SSR messages that support PPP have recently been standardized, which are level 1 messages related to satellite orbit and clock corrections and vertical and slant ionospheric delay correction will be added in future (RTCM 2016, Kim & Park 2017).

The above SSR messages, as shown in Table 1 and Fig. 2, are designed to provide the satellite orbit, clock error, and ionospheric and tropospheric error components in different intervals (Lim et al. 2017). As shown in Fig. 3, the satellite orbit error correction ($\overrightarrow{\delta O}$) provided in SSR message is in the radial (e_{radial}), along-track (e_{along}), and cross-track (e_{cross}) direction, so the coordinates need to be converted to the ECEF direction ($\overrightarrow{\delta X}$) using Eq. (1). In addition, if SSR message is generated in long intervals, the time delay should be compensated by applying the rate of change of each correction.

$$\overrightarrow{\delta X} = [e_{radial} \quad e_{along} \quad e_{cross}]\overrightarrow{\delta O} \tag{1}$$

In order to apply the satellite orbit error correction received by SSR to user measurements, the user estimates the broadcast satellite orbit, and corrects the broadcast satellite orbit by using satellite orbit correction as shown in Eq. (2).

$$\overrightarrow{r^s} = \overrightarrow{r^s_{brdc}} - [e_{radial} \quad e_{along} \quad e_{cross}]\overrightarrow{\delta O} \tag{2}$$

where $\overrightarrow{r^s}$ is the corrected satellite coordinates, and $\overrightarrow{r^s_{brdc}}$ is the broadcast satellite coordinates. Using this corrected satellite orbit, the users can accurately calculate the distance between the receiver and satellite (R) included in the observation measurements.

The satellite clock error provided in SSR message consist of C_0, C_1, and C_2 polynomial coefficient, and the units of C_0, C_1, and C_2 are m, m/s, and m/s^2, respectively. Using the satellite clock correction received at t_0, the correction at t can be calculated by using Eq. (3).

$$\delta\tilde{C} = C_0 + C_1(t - t_0) + C_2(t - t_0)^2 \tag{3}$$

The error term not reflected in the model of Eq. (3) is included in the High-rate clock correction (δC_{HR}) and is frequently provided, and the satellite clock error term (δt^s_{ssr}) is calculated by adding the value of Eq. (3) as shown in Eq. (4).

$$\delta t^s_{ssr} = \delta\tilde{C} + \delta C_{HR} \tag{4}$$

The SSR tropospheric correction provides tropospheric delay at grid points and the users interpolate it according to their position. The SSR tropospheric correction is not yet standardized, but according to the literature (Kim & Park 2017), it provides GPS Week Second, latitude, longitude, altitude, Zenith Hydrostatic Delay (ZHD), and Zenith Wet Delay (ZWD) information. The tropospheric delay (δT^s_{ssr}) is obtained by converting the delay value provided in zenith direction to the value in line-of-sight direction and mapping function is used to convert to Observation Space Representative (OSR) as shown in Eq. (5).

$$\delta T^{s}_{ssr} = m_h \times ZHD + m_w \times ZWD \tag{5}$$

where m_h is the mapping function of dry delay, and m_w is the mapping function of wet delay.

The SSR ionospheric correction provides GPS Week Second, latitude, longitude, altitude, PRN, and Slant Total Electron Content (STEC) at grid points and the users interpolate it according to their position. Ionospheric delay (δI^{s}_{ssr}) is calculated by converting the STEC considering satellite signal frequency (f) as shown in Eq. (6).

$$\delta I^{s}_{ssr} = \frac{40.3}{f^2} \cdot STEC \tag{6}$$

4. INTEGRATION OF SSR INTO NETWORK RTK SYSTEM

The SSR message uses corrections separated by each GNSS error source, which does not vary significantly with time, so the transmission interval varies from 1 to 60 seconds and position performance does not sensitively degrade even if some data are missing. Although the format, transmission interval, and application method of SSR corrections are not compatible with Network RTK system, as described above, if systems that mainly operate based on Network RTK cannot receive corrections temporarily, it is inevitable to use PPP correction to minimize the performance degradation. For integrated operation from this perspective, we converted SSR messages used in PPP-RTK into OSR format applicable to Network RTK, and performed a simulation to predict the performance when applied those to Network RTK users with a time delay of 30 seconds. However, since the simulation was performed in terms of validity of the correction, inherent problems of carrier phase based positioning such as cycle-slips were not considered, and the performance of a single frequency receiver based on SSR corrections was simulated in case of time delay after ambiguity resolution by Network RTK.

In order to perform a simulation for predicting ORS performance under time delay, among the reference stations of the National Geographic Information Institute, we configured a network in which Gunwi is the main reference station, Yeongdoek, Daegu, Gimcheon, and Yecheon are the sub-reference stations, and Cheongsong is the user, and generated simulation data using navigation data from 4:30 ~ 5:30 (UTC) on July 1, 2016. Since we do not evaluate the performance of PPP correction estimation, but evaluate the performance of SSR corrections, which are transmitted at a relatively low transmission interval, converted into OSR, we generated estimates by each GNSS error source by including actual error provided by the system such as IGS in true error used in the simulation and calculated the error projected onto the user space in the range-domain and the position-domain by applying the scheduling time interval. Here, we assumed that the ambiguity was resolved before the 30-second time delay, and a time delay of 30 seconds was applied to all measurements to confirm the statistical characteristics.

According to IGS data center, the accuracy of Ultra-Rapid and Rapid orbit products is 2.5 ~ 5 cm and that of clock products is 50 ps ~ 3 ns (IGS 2018), A Gaussian noise with a standard deviation of 2.5 cm and 75 ps was inserted into satellite orbit and clock, respectively. In other words, the satellite orbital error correction in SSR message is provided in radial, along-track, and cross-track directions, and since the simulation data is generated based on the ECEF axis, the difference ($\overrightarrow{\delta X}$) between satellite position ($\overrightarrow{X_{sp3}}$) from IGS SP3 data and ECEF satellite position ($\overrightarrow{X_{brdc}}$) obtained from navigation data was computed and converted to ($\overrightarrow{\delta O}$) in the radial, along-track, and cross-track direction, and the noise ($\overrightarrow{\delta\epsilon_{\delta O}}$) defined above is inserted in the generated SSR orbital correction as shown in Eq. (8).

$$\overrightarrow{\delta X} = \overrightarrow{X_{brdc}} - \overrightarrow{X_{sp3}} \tag{7}$$

$$\overrightarrow{\delta X} = [e_{radial} \quad e_{along} \quad e_{cross}]\overrightarrow{\delta O} + \overrightarrow{\delta\epsilon_{\delta O}} \tag{8}$$

where $\overrightarrow{\delta\epsilon_{\delta O}} \sim N(\vec{0}, 0.025^2 I)$ and I is a 3×3 matrix.

The satellite clock error correction (δC) is also calculated by the difference between the error (C_{brdc}) estimated from broadcast navigation message and the error (C_{sp3}) from SP3 data.

$$\delta C = C_{brdc} - C_{sp3} \tag{9}$$

The coefficients are calculated by approximating the error calculated by using Eq. (9) to the second-order polynomial function of Eq. (3), and we calculate the coefficients by the least-square method for data of the last 10 seconds, which is the actual broadcasting interval. According to RTCM standard message, since the High-rate clock correction must be transmitted every second in addition to the above satellite clock correction, the High-rate clock correction (δC_{HR}) is transmitted as the difference between the clock error (δC) calculated by using Eq. (9) and the clock error ($\delta\tilde{C}$) calculated by the second-order polynomial equation as shown in Eq. (10).

$$\delta C_{HR} = \delta C - \delta\tilde{C} \tag{10}$$

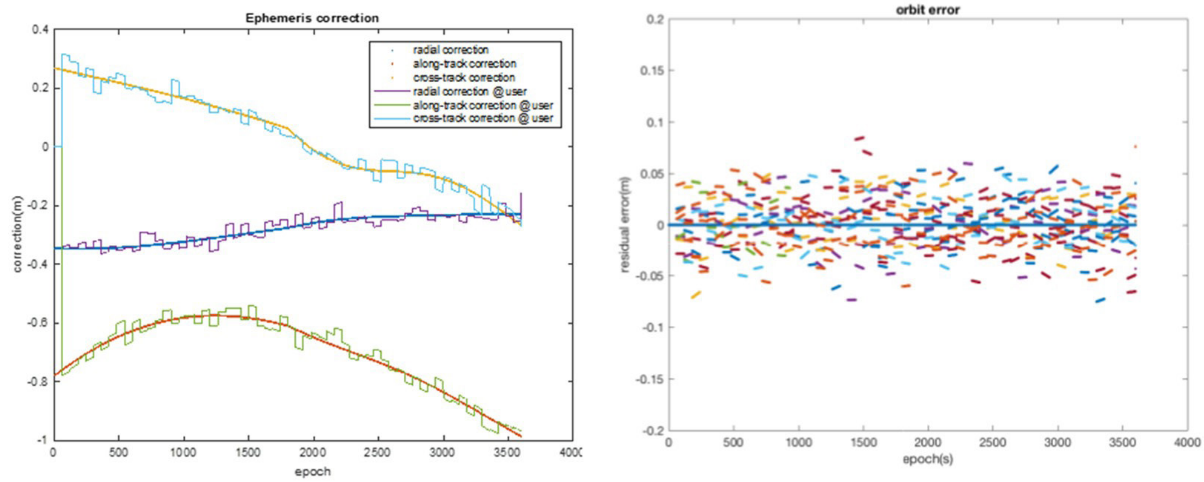

Fig. 4. SSR ephemeris correction (left) and ephemeris correction error at user side (right).

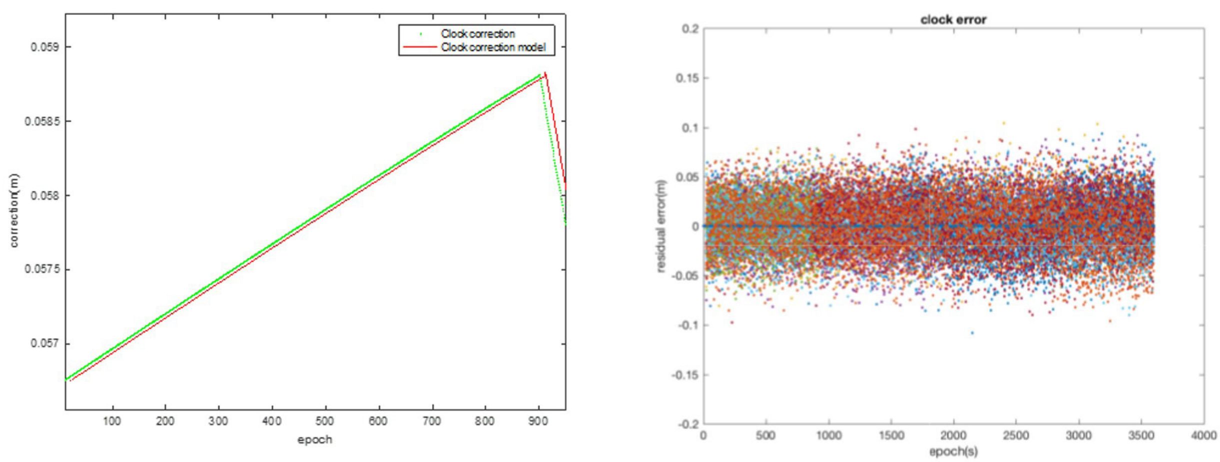

Fig. 5. SSR clock correction (left) and clock correction error at user side (right).

In addition, the velocity component is transmitted along with the satellite clock and orbit corrections in 10-second intervals, and since satellite orbit and clock in Ultra-Rapid products from IGS are generated in 15-minute intervals, assuming that the velocity component is estimated at 15-minute intervals, noise equal to $\frac{\sqrt{2}}{15 \cdot 3600}$ times of noise of the satellite orbit and clock from IGS was inserted as the estimation error.

The results of comparing SSR satellite orbit and clock error with 30-second time delays and the estimates from the user are shown in Figs. 4 and 5. In case of satellite orbit error, a stepwise error occurs every time satellite ephemeris is updated, while the satellite clock error takes the form of random noise.

In case of the ionospheric error, we collected the GNSS measurements from the reference stations in network, and then generated the plane model of the ionospheric error based on estimated ionospheric error at the ionospheric pierce point. Then, we generated the ionospheric error at each grid point based on the plane model, and the users compute the ionospheric error correction by interpolating the ionospheric error at each pierce point and apply it to satellite signal. The block diagram for this process is shown in Fig. 6, and the plane model of the ionospheric error generated by the method above and the results of calculating the ionospheric residual errors at each grid point are shown in Fig. 7.

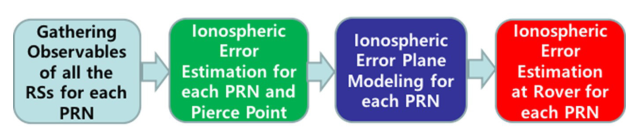

Fig. 6. SSR ionospheric correction modeling process.

In case of the tropospheric error, dry and wet delay errors

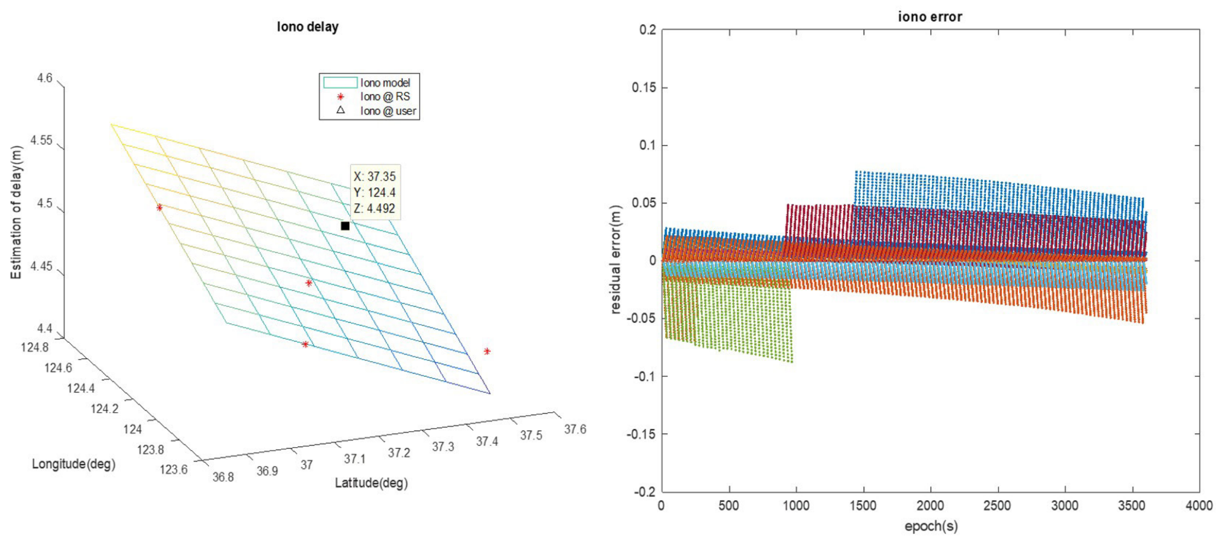

Fig. 7. Plane model of ionospheric error (left) and ionospheric residual error at user side(right).

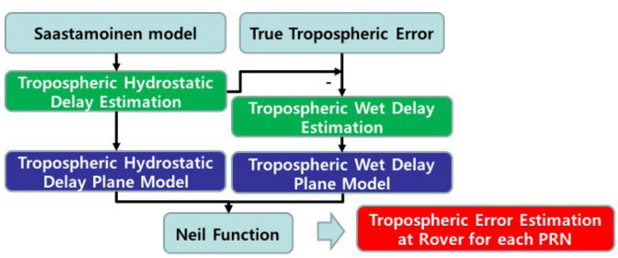

Fig. 8. SSR tropospheric hydrostatic and wet delay plane modeling process.

are provided for each latitude and longitude in the same manner as the ionospheric delay. We generated a plane model of tropospheric dry delay by using dry delay error obtained from Saastamoinen model, and generated a plane model of wet delay error by regarding the wet delay error as the value obtained by subtracting the dry delay error calculated by the Saastamoinen model from the tropospheric delay error in the simulation. Subsequently, the tropospheric correction at the user position is generated by combining the tropospheric dry and wet delay at each grid point based on the plane model. The block diagram for this process is shown in Fig. 8, and the plane model of the tropospheric error generated by the method above and the results of calculating the tropospheric residual errors at each grid point are shown in Figs. 9 and 10.

Since the purpose of this paper is to analyze whether SSR message helps to improve the performance of network RTK users who have not received network RTK corrections for about 30 seconds. We analyzed the positioning error caused by the residual error by each satellite in the range-domain obtained above. In other words, we assumed that the user carrier phase ambiguity was precisely resolved during the

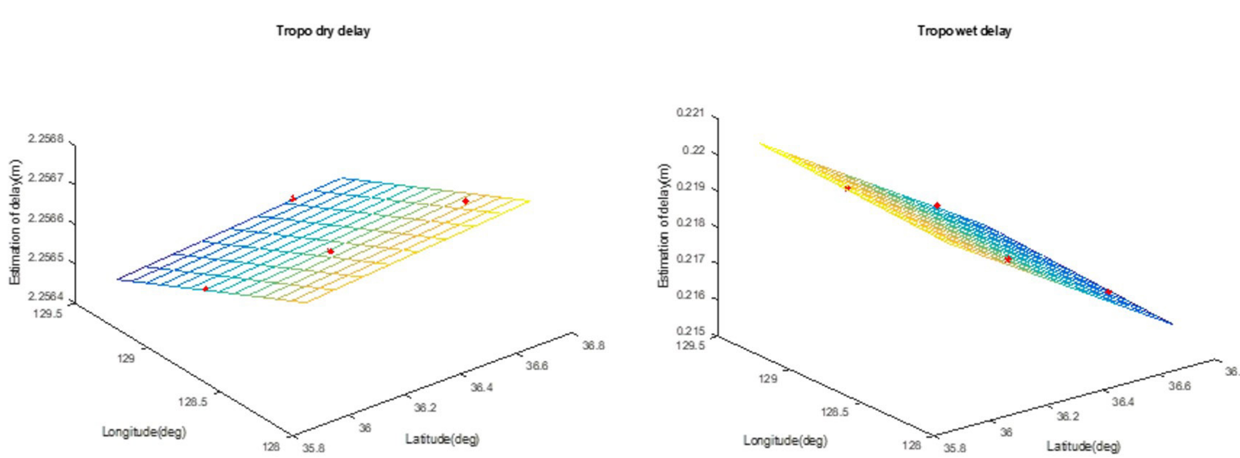

Fig. 9. Plane model of tropospheric dry part (left) and wet part(right).

valid period of Network RTK, and a time delay of 30 seconds occurred in normal Network RTK operation. As shown in Fig. 11, during this 30-second time delay, the satellite clock correction is calculated by the difference between the sum of the satellite clock provided by SSR message and the High Rate satellite clock and the broadcast satellite clock, and the difference between the satellite orbit provided by SSR message and the broadcast satellite orbit is calculated as the satellite orbit correction, and both corrections are projected into the range-domain. In case of the ionospheric and tropospheric errors, these errors for each satellite are calculated by projecting the corrections provided in SSR message into range-domain. As such, range-domain corrections by each error source for satellites used in network RTK solution is calculated by converting SSR correction to OSR correction and the rate of change of each correction is used to compensate for time delay.

The results of the above simulation, as shown in Table 2, show that the Root Mean Square (RMS) of residual of satellite orbit and clock error is 1.34 cm, the RMS of residual of ionospheric error is 1.77 cm, the RMS of residual of tropospheric error is 0.45 cm, and RMS of the sum of total errors is 4.16 cm. In addition, the time series of residual distribution of each satellite in the range-domain is shown in Fig. 12.

As a result of analyzing the positioning results, after projecting the range-domain residual of SSR message due to the time delay obtained by the simulation into the position-domain using the user observation matrix, this is equivalent to the positioning results obtained by compensating the time delay with the velocity component of SSR message under the 30 second time delay. As a result of estimating the degree of performance degradation by compensating the time delay with the velocity component of the correction by each error source generated using the SSR message, as shown in Fig. 13 and Table 3, We confirmed that horizontal residual error is 5 cm RMS, 8.7 cm 95% and 8 cm RMS, 16 cm 95% for vertical residual error. This is a significant amount when compared to the horizontal and vertical RMS of 0.3 cm and 0.6 cm, respectively, for Network RTK without time delay for the same data, but is considerably smaller compared to the 0.5 ~ 1 m accuracy of DGPS or SBAS. Therefore, maintaining Network RTK mode using SSR rather than switching to code-based DGPS or SBAS mode due to failure to receive correction information for 30 seconds is considered to be favorable in terms of maintaining system accuracy and recovering performance by fast integer ambiguity resolution

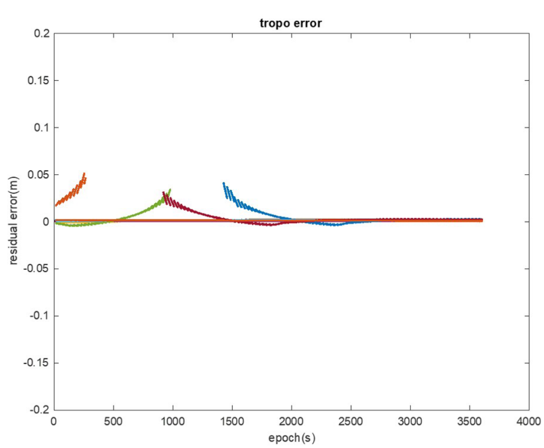

Fig. 10. Tropospheric modeling error at user side.

Table 2. Error RMS for each component and total error.

Error source	Clock	Orbit	Iono	Tropo	Total
RMS (cm)	1.40	1.34	1.77	0.45	4.16

Table 3. Statistics of SSR-aided positioning results under 30 second data-cutoff.

	Mean (cm)	RMS (cm)	95% (cm)	Max (cm)
Horizontal error	0.99	4.94	8.70	17.47
Vertical error	0.78	7.92	16.23	36.95

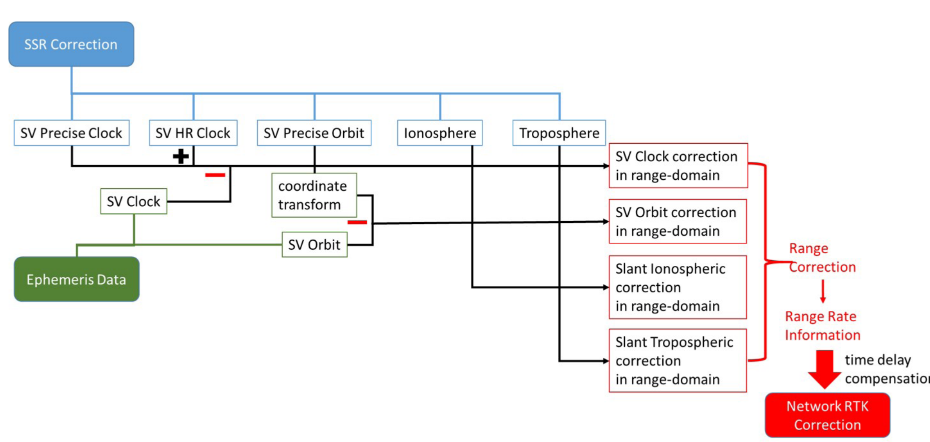

Fig. 11. Concept of integrating SSR into network RTK correction for latency compensation.

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when the communication channel is recovered.

5. CONCLUSIONS

This paper describes the possibility of contributing to stable Network RTK operation by analyzing the characteristics of SSR message proposed for PPP and predicting its performance through simulation. The Network RTK is a practical navigation technique that extends the availability of RTK that provides high positioning accuracy at levels of cm~dm through a network of reference stations, but have to continuously receive corrections to maintain a high level of positioning accuracy. On the other hand, in case of SSR, which is recently under standardization for PPP service, corrections for each error component are transmitted at different intervals, information about the rate of change of each component is also provided to compensate the time delay. Therefore, in the event of time delays of more than 30 seconds, the robustness against time delay is higher in SSR corrections than general Network RTK corrections. In order to review the possibility of integrating Network RTK, which is a practical positioning technique, with SSR with time delay robustness, a performance prediction was conducted using GNSS measurements generated by simulation based on the location information of 6 stations from the National Geographic Information Institute. By generating and scheduling SSR corrections from the simulation measurements, we confirmed residuals that could occur when users did not receive Network RTK corrections for 30 seconds. As a result of calculating the residuals, the residual RMS due to generating and scheduling corrections was about 4.16cm in the range domain, and when projected to the position domain, the RMS errors were 4.94 cm horizontally and 7.92 cm vertically. These are significant amounts compared to 0.3 cm horizontally and 0.6 cm vertically, which are network RTK performance without time delay for the same data, but is considerably smaller compared to the 0.5 ~ 1 m accuracy of DGPS or SBAS. Therefore, maintaining Network RTK mode using SSR corrections rather than switching to code-based DGPS or SBAS mode due to failure to receive network RTK corrections for 30 seconds is considered to be favorable in terms of maintaining system accuracy and recovering performance by fast integer ambiguity resolution when the communication channel is recovered.

Although this paper only described about mitigating Network RTK performance degradation using SSR messages

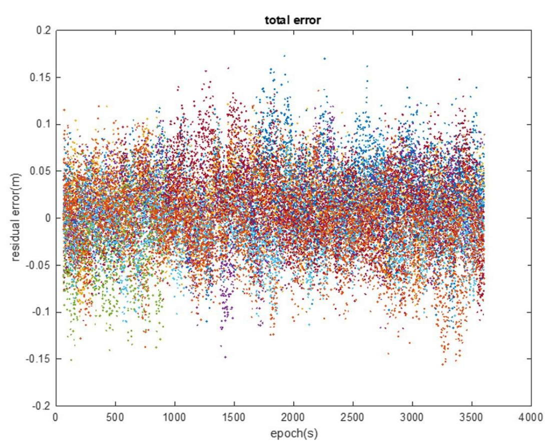

Fig. 12. Total residual error in range-domain at user side.

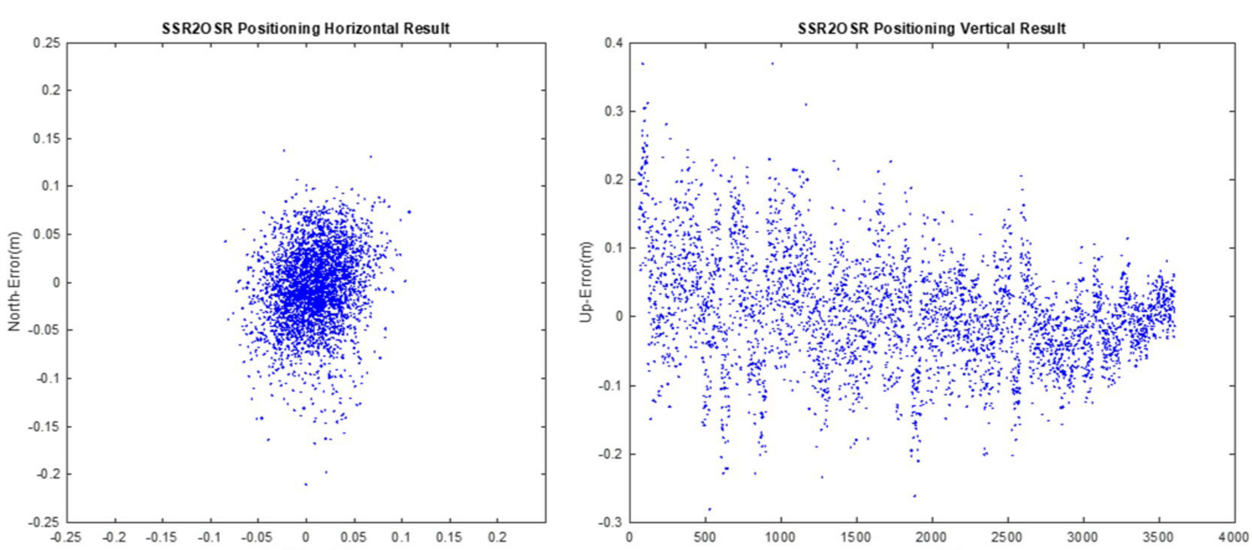

Fig. 13. Total residual error in position-domain at user side.

for missing data for a long time, since synergies are expected between Network RTK and SSR correction in various aspects such as improving ambiguity resolution performance, keeping and restoring ambiguity, and combining both corrections, it is necessary to examine methods to combine both corrections through various case studies in future.

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