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Developing Regional Precise Positioning Services Using the Legacy and Future GNSS Receivers

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ABSTRACT

This paper presents an overview of technical developments within the CRCSI-funded research on "Delivering Precise Positioning Services in Regional Areas" undertaken by the authors since mid-2007. The research aims to address the technical and business issues that currently constrain GPS-based local area RTK precise positioning services so as to operate in future across larger regional areas, and therefore support services in agriculture, mining, utilities, surveying, construction, and others. Selected research findings to be presented in this paper cover the following aspects. (1) An overall technical framework has been proposed to transition the current RTK services to future larger scale coverage. The framework enables mixed use of different reference GNSS receiver types, dual- or triple-frequency, single or multiple systems, to provide RTK correction services to users equipped with any type of GNSS receivers. (2) Research on data processing algorithms appropriate for triple-frequency GNSS signals has demonstrated some key performance benefits of using triple carrier signals for reliable RTK positioning over long distances. (3) A server-based RTK software platform is being developed to allow for user positioning computations at server nodes instead of on the user's device. (4) An optimal deployment scheme for reference stations across a larger-scale network has been suggested, given restrictions such as inter-station distances, candidates for reference locations, and operational modes. For instance, inter-station distances between triple-frequency receivers can be extended to 150km, doubling the distances between dual-frequency receivers in existing RTK network designs.

Keywords: GNSS, RTK, Server-based RTK, Three carrier ambiguity resolution (TCAR)

1. INTRODUCTION

In Australia, Global Navigation Satellite Systems (GNSS)–based precise positioning services have been developed and improved in order to support the mining, agriculture and construction industries, which are the major sectors responsible for the recent growth in Australia's economy. For instance, GNSS-based solutions are used in agriculture for automated tractor guidance systems and topographic mapping, and have improved farm productivity by about 30%. The basic technology is known as real-time kinematic (RTK) positioning. The traditional RTK technique has been used for private single-base RTK systems that typically cover individual business/farm operations. A disadvantage of this approach is the proliferation of local-area single site solutions, for example over 1000 cropping farms were estimated to have purchased GNSS reference stations and private radio solutions since 2002. The total expenditure had been estimated at approximately $20M. Many of these private systems overlap with each other and provide no access to mobile users working nearby.

The key limitation of dual-frequency carrier phase-based RTK positioning systems is that the service distance between a reference or base station and a user or rover receiver must be kept to within a few tens of kilometres because rapid and reliable carrier phase ambiguity resolution (AR) becomes increasingly difficult as the inter-receiver distance increases (Rizos & Han, 2003). This phenomenon is mainly caused by the effects of distance-dependent biases, such as orbital errors, and ionospheric and tropospheric delays in the double-differenced (DD) measurements. In current network-RTK implementations using, for example, the virtual reference station (VRS) techniques (Chen et al, 2001; Zhang & Lachapelle, 2001), the inter-station distance may be extended to as much as 70 to 90km. Hence, network-based RTK has resulted in a reduction of the investment costs necessary to start a RTK positioning service, since the number of reference stations can be reduced by at least 3 to 4 times. For instance, about 10 reference stations are needed to cover a medium-sized city with an area of about 10,000 square kilometres using a typical 20km single-base RTK system, whereas deployment of the VRS system with 3 to 4 reference stations may provide a service across the same coverage area. However, such networks are typically available in urban/suburban areas with high population density and good internet and mobile communication infrastructures. The SunPOZ real-time GPS service, for example, is currently limited to south east Queensland, with the five station SunPOZ network covering an area of about 11,000 square kilometres (Cislowski & Higgins, 2006). Nevertheless, if the coverage of the SunPOZ network were extended only to cover the inhabited areas of Queensland at this density, the number of reference stations that would be needed would be of the order of 150 to 200, costing over ten million dollars in capital expenditure, and a significant on-going cost for operations. This large positioning infrastructure cost is quite an impediment compared to the states of Victoria and NSW, where high density networks of GPS reference stations can be deployed in a relatively cost effective manner.

The CRCSI-funded research project "Delivering Precise Positioning Services in Regional Areas" has been undertaken by the authors since mid-2007. The research aims to address the technical and business issues that currently constrain GPS-based local area RTK precise positioning services, so as to operate in future across larger coverage areas, and therefore support services for agriculture, mining, utilities, construction industries, and other users, across the whole of Queensland. This paper presents selected research findings of this project. Section 2 will describe an overall technical framework that has been proposed to transition the current RTK services to future larger scale services. Section 3 outlines data processing algorithms appropriate for triple-frequency GNSS signals that have demonstrated some key performance benefits for reliable RTK positioning over long distances. Section 4 describes a server-based RTK software platform that would allow for user positioning computations at server nodes instead of on the user's device. Section 5 introduces a software tool developed for optimal placement of reference stations in a network, given constraints such as inter-station distances, candidates for reference locations, and operational modes. Section 6 is a summary of the research findings of the project thus far.

2. An Overall Technical Framework for Regional RRK Services

New Global and Regional Navigation Satellite Systems (GNSS/RNSS) from the USA (modernized GPS), Europe (Galileo), Russia (modernized GLONASS), China (Compass), Japan (QZSS) and India (IRNSS) will progressively become operational over the next five years. These system will all operate with three or more frequencies, and will significantly increase the number of visible satellites that can be tracked, bringing improved satellite availability (particularly in obstructed environments), better error mitigation capabilities, quicker position-fix times, faster and more reliable ambiguity resolution over longer inter-receiver distances, improved positioning integrity, etc.

However, any of the existing GPS satellites over their lifespan of as long as 15 years in space will continue to transmit signals on the L1 and L2 frequencies only, while new generation navigation satellites of different GNSS/RNSS may broadcast three or more frequency signals, such as GPS IIR-M satellite and Compass-G2 satellite launched in April 2009. Therefore, in the foreseeable future, both dual-frequency and triple-frequency receivers would be used in one reference network and by different rover users. In other words, we will have to deal with situations such as legacy dual-frequency reference stations are used to provide the differential correction services to new triple-frequency users, or new triple-frequency reference stations will need to provide services to legacy dual-frequency users. The more general situation is the mixed use of dual-frequency and triple-frequency measurements, from different satellites, at the network level processing system and for user end systems.

In addition to continuously operating reference station (CORS) networks operating in the different states of Australia, in early 2007 the Australian Government announced funding for the AuScope GNSS network under the National Collaborative Research Infrastructure Strategy (NCRIS). AuScope is designed primarily for geoscientific applications, however this network can obviously offer additional downstream benefits such as augmenting the real-time kinematic positioning services provided by state government or private CORS networks.

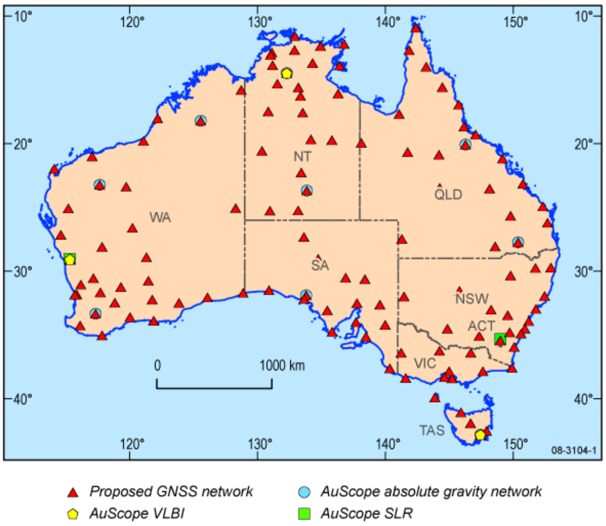

Fig. 1 AuScope Geospatial infrastructure including candidate GNSS network (http://www.ga.gov.au)

The CRCSI project has as one of its goals to develop underlying strategies to incorporate the AuScope stations as 'backbone' reference network and to integrate the AuScope CORS with networks such as Queensland SunPOZ, NSW's CORSnet, and Victoria's GPSnet, as well as with privately operated GPS base stations. Thanks to NTRIP technology, networking all the servers or stations, and collecting real-time GNSS data streams at a central server is no longer technically challenging.

The overall objective of the research was to define the critical technical issues that needed to be addressed in order to deliver improved precise regional positioning services in rural areas, including:

- How to incorporate future generation GNSS systems and multiple frequency signals into regional GNSS precise positioning services in Australia.
- How to make use of real time data streams from different reference networks or stations, current and future, to improve existing centimetre-level positioning services, and extend these services across a much wider geographic area.
- How to optimally deploy dual- and triple-frequency reference stations in order to deliver positioning services in the most cost effective manner.
- How to serve different RTK users equipped with GNSS receivers of different types: single-, dual- and triple-frequencies, legacy and modern receivers, with or without dedicated user RTK firmware.

Research outcomes for each of the above issues are described in the later sections. As illustrated in Figure 2, the overall technical framework for the regional scale positioning services operates through four major components: reference networks, network RTK data processing platform, computer server/service provider and RTK user terminal. The functions of each component mainly include the following:

- CORS networks consist of tens of 'backbone' reference stations equipped with advanced GNSS receivers, together with many reference stations equipped with legacy receivers. All stations are assumed to be able to provide real time data streams to the regional network RTK data processing platform.
- Network RTK software platform will process real time data streams from all participating CORS stations, resolve integer ambiguities for all the baselines and generate Zenith Troposphere Delay (ZTD) solutions for each station in real time, and create precise ionospheric grid corrections using double-differenced phase measurements.
- Computer server/service provider functions in two different ways. It can play the role of a service provider to distribute the network correction data to participating rover user terminals – it is then up to users to compute own positions. The alternative is that the computer server uses the network grid corrections and real stream data from users to compute user position solutions and send them back to the users – a so-called "reverse RTK" positioning mode.
- RTK user terminal can either transmit their data to a computer server and get real time position solutions back, or receive the network corrections from a service provider and compute their own positions, as in the case of existing rovers equipped with dedicated RTK software.

The major advances of the above regional RTK framework with respect to the existing network-RTK systems are two-fold: (1) the network-RTK data processing platform can resolve the integer ambiguities over inter-station distances of hundreds of kilometres. Such a platform can process any type of GNSS data: dual- or triple-frequency measurements, one or more systems, etc; (2) any number of computer servers can link between the network processing central server and different groups of RTK users, to produce user positions in real time. This concept is described as a server-based RTK (Lim & Rizos, 2008).

In the country with vast territory like Australia or China, there exist many reference stations and networks being operated in an uncoordinated manner by different private and public owners. Instead of replacing all the isolated systems and services, the proposed framework make use the data streams from all the stations, current and future, for improved precise positioning services over much wider geographic areas.

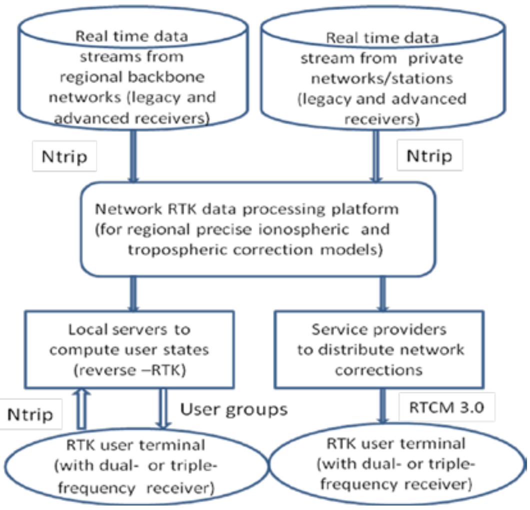

Fig. 2. Regional GNSS positioning framework

3. Benefits of Future GNSS Systems On the Regional RTK Services

Future Global Navigation Satellite Systems (GNSS) and augmentations, such as the USA's modernized Global Positioning System (GPS), the Russian Glonass, the E.U.'s Galileo system, the Japanese Quasi-Zenith Satellite System (QZSS) and China's Compass system, will all operate with three or more frequencies, as shown in Figure 3 (from Hein et al, 2007). Significant research efforts have been made in the past ten years to develop data processing algorithms that use the third GNSS signals to improve RTK services, including contributions by Forssell et al (1997), Vollath et al (1998), Han & Rizos (1999), De Jonge et al (2000), Hatch et al (2000), Teunissen et al (2002), Vollath (2004) and Feng & Rizos (2005). Within the scope of this CRCSI research, Feng (2008), Feng & Li (2008a,b) and Feng & Rizos (2009) have systematically developed the geometry-free and geometry-based three carrier ambiguity resolution (TCAR) algorithms and examined the performance potential of multiple-frequency GNSS signals on reliable ambiguity resolution (AR) over longer inter-receiver distances.

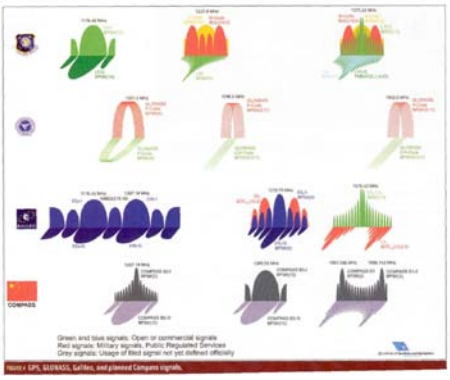

Fig. 3. GPS, Glonass, Galileo and Compass signals and frequencies (Hein et al, 2007).

Table 1. Summary of the Geometry-free and Geometry-based TCAR models and solutions

<table>
<tr><td colspan="2">Definitions:
$$\left.\begin{aligned}\boldsymbol{\Phi}&=(\Delta\phi_1\quad\Delta\phi_2\quad\Delta\phi_5)^T\\ \mathbf{P}&=(\Delta P_1\quad\Delta P_2\quad\Delta P_5)^T\\ \mathbf{N}&=(\Delta N_1\quad\Delta N_2\quad\Delta N_5)^T\\ \boldsymbol{\Lambda}&=\mathrm{diag}(\lambda_1\quad\lambda_2\quad\lambda_5)\end{aligned}\right\}\qquad \left.\begin{aligned}\mathbf{Z}_{(i,j,k)}&=\frac{1}{i\cdot f_1+j\cdot f_2+k\cdot f_5}(i\cdot f_1\quad j\cdot f_2\quad k\cdot f_5)\\ \mathbf{z}_{(i,j,k)}&=(i\quad j\quad k)\end{aligned}\right\}\qquad \left.\begin{aligned}\Delta N_{(i,j,k)}&=\mathbf{z}_{(i,.j,k)}\mathbf{N}\\ \lambda_{(i,j,k)}&=\frac{\lambda_1\lambda_2\lambda_5}{i\cdot\lambda_2\lambda_5+j\cdot\lambda_1\lambda_5+k\cdot\lambda_1\lambda_2}\end{aligned}\right\}$$
where (i,j,k) and (l,n,m) represent different groups of integers.</td></tr>
<tr><td>Geometry-free models:
The 1st and 2nd extra-widelanes (EWL) are chosen from
$$\Delta P_{(l,m,n)}-\Delta\phi_{(i,j,k)}=[Z(l,m,n)\quad -Z(i,j,k)]\begin{bmatrix}P\\ \Phi\end{bmatrix}$$
The 3rd signal is a choice of a narrowlane or medium-lane from
$$\Delta\tilde{\phi}_{(l,m,n)}-\Delta\phi_{(i,j,k)}=Z(l,m,n)\Phi+\lambda_{(l,m,n)}\Delta N_{(l,m,n)}-Z(i,j,k)\Phi$$
where $\Delta N_{(i,m,n)}$ is known from the 1st and 2nd EWLs</td><td>Geometry-based models:
One combined code measurement with the lowest total noise level is chosen from
$$\Delta P_{(l,n,m)}=Z(l,n,m)P$$
Two extra-widelanes and one narrowlane phase observables with the lowest total noise levels are chosen from
$$\Delta\phi_{(i,j,k)}=Z(i,j,k)\Phi$$</td></tr>
<tr><td>GPS L1, L2 and L5:
Code: $\Delta P_{(1,1,0)}$ or $\Delta P_{(0,1,1)}$
1st EWL: $\Delta\phi_{(0,1,-1)}$
2nd EWL: $\Delta\phi_{(1,-5,4)}$
ML/NL: $\Delta\phi_{(1,0,0)}$ (with $\Delta\tilde{\phi}_{(1,-1,0)}$)</td><td>GPS L1, L2 and L5:
Code: $\Delta P_{(1,1,0)}$, $\Delta P_{(0,1,1)}$
1st EWL: $\Delta\phi_{(1,-6,5)}$
2nd EWL: $\Delta\phi_{(1,-5,4)}$
ML/NL: $\Delta\phi_{(4,0,-3)}$ (with $\Delta\phi_{(1,-1,0)}$)</td></tr>
<tr><td>Ambiguity resolution algorithm:
Averaging over multiple epochs and rounding to the nearest integers</td><td>Ambiguity resolution algorithm:
Integer Least Squares estimation</td></tr>
<tr><td>Remarks:
The solutions are distance-independent, but AR of the third ambiguity takes observation of several minutes of averaging for 100% success, and thus is more suitable for network-based processing</td><td>Remarks:
The integers are resolved with ionosphere-reduced combined signals, suffering from residual tropospheric errors, thus solutions are distance dependent, but all ambiguities should be resolved with single epoch measurements.</td></tr>
</table>

Table 1 summarises the key geometry-free and geometry-based AR models and algorithms. Table 2 shows the AR success rates for the 1st EWL of the geometry-free method from measurements of a single epoch, assuming the double-differenced P1 code noise level of 0.6cm.

Table 2. Total noise level and success probability of the 1st EWL signal (with two different phase noise levels).

GNSS	1st EWL	$\sigma_{\Delta\phi_1} =$ 0.5cm	%	$\sigma_{\Delta\phi_1} =$ 0.7cm	%
GPS L1,L2,L5	$\Delta\phi_{(0,1,-1)}$	0.077	100	0.0819	100
Galileo L1,E6,E5A	$\Delta\phi_{(0,1,-1)}$	0.146	99.96	0.1490	99.92
Galileo L1,E6, E5B	$\Delta\phi_{(0,1,-1)}$	0.105	100	0.1084	100
Compass E1, E6,E5B	$\Delta\phi_{(0,1,-1)}$	0.091	100	0.095	100
Compass E2, E6,E5B	$\Delta\phi_{(0,1,-1)}$	0.091	100	0.095	100

Table 3 gives the AR success rates for the 2nd EWL of the geometry-based method with single epoch measurements, assuming normal phase noise level of 5mm and the worse noise level of 7mm respectively (Feng & Li, 2009). Both tables show that the AR for the 1st EWL and 2nd EWLs is straightforward and reliable, achieving almost 100% success using just single epoch measurements. With the geometry-free model, resolving the third ambiguity takes observations of several minutes of averaging for 100% success, but is suitable for any scale network-based processing using continuous observations (Feng & Li, 2008a; Li et al, 2009). In the geometry-based model for the narrowlane or medium-lane combination, the systematic effects of the ionospheric biases are reduced or eliminated, and the AR success depends on the effect of tropospheric errors, which could be corrected via interpolation of ZTD solutions at each station (as suggested in Zheng & Feng, 2005) to the RMS accuracy of 1cm or so, over inter-receiver distances of about 100km. As a result, resolution of the third ambiguity with a high success rate is achievable from single epoch measurements using the geometry-based model in which integers are determined and searched via least squares methods, such as LAMBDA. To further understand the effects of the relative ZTD errors on AR success rates, we added 1, 2 and 3 cm relative ZTD errors which are mapped onto each satellite in processing of a 24-h GPS data set from the US CORS network (P474-P478). Tab. 4 shows the effects of added ZTD errors on the AR success rates, resulting from ILS solutions using measurements from every single epoch. The result is obtained at a specific location on that day, but reflects the effect to a reasonable degree. Fig. 4 is the flowchart of the geometry-free and geometry-based TCAR, from 1st EWL and 2 EWL and third ambiguity, and of the various outputs.

Table 3. Total noise level and success probability of the 2nd EWL signal (with two different ionospheric bias terms 0.20m, and 1.3m).

GNSS	2nd EWL	**$\Delta\delta I=$ 0.20m**	%	**$\Delta\delta I=$ 1.3m**	%
GPS L1,L2,L5	$\Delta\phi_{(1,-6,5)}$	0.160	99.82	0.182	99.40
Galileo L1,E6,E5B	$\Delta\phi_{(1,-3,2)}$	0.0823	100	0.167	99.72
Galileo L1,E5,L5	$\Delta\phi_{(1,-4,3)}$	0.109	100	0.157	99.86
Compass E1, E6 E5B	$\Delta\phi_{(1,-5,4)}$	0.136	99.98	0.152	99.90
Compass E2, E6 E5B	$\Delta\phi_{(1,-5,4)}$	0.137	99.97	0.195	98.87

Table 4.Snapshot of effects of relative ZTD errors on ambiguity resolution success rates

Relative ZTD error	0	1cm	2cm	3cm
Number of correct integer-fix epochs	5756	5754	5740	5715
Success rates % (out of 5760)	99.93	99.90	99.65	99.22

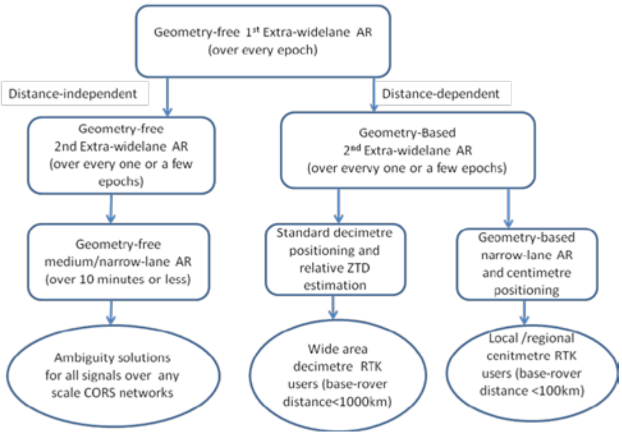

Fig. 4. Flowchart of geometry-free and geometry-based TCAR processing.

4. Regional Network RTK Software Platform

As outlined in Section 2, the core of the regional positioning services is a regional network-RTK data processing platform. Figure 5 shows the four processing components of such a platform:

- Shared Software Platform, which links all participating network servers and reference stations via the Internet, collecting raw measurements and providing these data streams to the following processors (this component was developed with the support of CRCSI project 1.12).

- Background Processor with the Bernese software to generate ZTD estimates on a half-hourly basis, which can then be provided to the network-based RTK processing as a priori information.
- Network-RTK processor, which has the capability of AR over all the baselines within the network with the ZTD values from the Background Processor, and generate ionospheric grid maps.
- Server-based RTK processor, which can make use of RTCM massages from rover receivers and typically the three (or more) nearest reference stations and the ZTD corrections to compute the user positions in real time. Figure 6 shows the concept of the server-based RTK. Depending on the user requirements, the server-based RTK can perform a various form of RTK including precise point positioning, traditional single-baseline RTK, network-RTK, reversed RTK, and reversed network RTK.

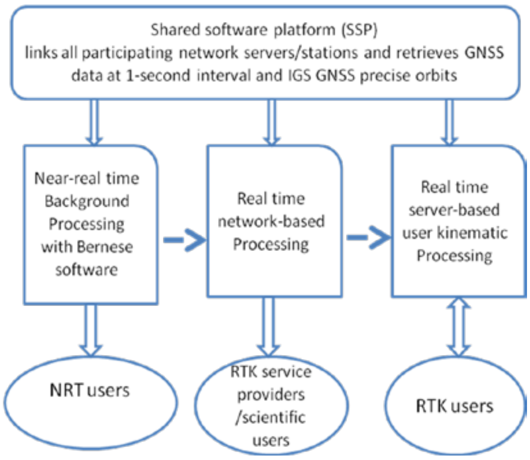

Fig. 5. Regional network RTK Platform

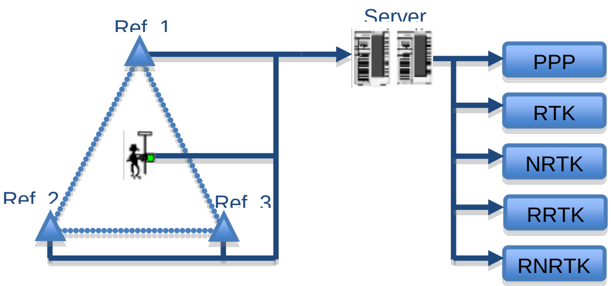

Fig. 6. Server-based RTK platform

In the above system, phase measurements from different satellite systems, quality dual-frequency receivers or triple-frequency receivers can contribute to the ionospheric and tropospheric grid modelling, which can then be supplied to any RTK user receiver capable of receiving either dual-frequency or triple-frequency measurements (or combination of the two).

The network-based RTK processor can operate independently of the Background Processing component, while the server-based RTK can also operate without the inputs from the network-based RTK processor.

5. Deployment of Dual- and Triple-Frequency GNSS Reference Stations

The above analysis indicates that the AR with three carrier observables could be reliably achieved without distance constraints within the network-level processing, which is followed by estimation of the ionospheric and tropospheric biases in DD phase measurements to form grid corrections. However, in order to specify to what degree the inter-station distances can be extended, care has to be taken of the effects of residual ionospheric and tropospheric errors on the rover user terminals anywhere within the network coverage. In the operation of network-RTK systems, the precisely predicted GPS orbits, such as ultra-rapid orbits, are available in real time to replace the broadcast GPS ephemerides, and the effect of orbit errors is no longer of concern (Kim & Langley, 2007).

The residual ionospheric errors after correction through interpolation of the ionospheric biases can remain distance-dependent and random in the DD phase measurements between a user receiver and its nearest (or virtual) reference station. With triple-frequency measurements, the ionospheric term may be corrected at the user end to centimetre accuracy, to become almost distance-independent (Feng, 2008). With dual-frequency measurements, for instance, i.e., L1 and L2 or L1 and L5, the effect of the residual ionospheric errors reaches a minimum with the ionosphere-reduced virtual observables, such as $\phi_{(4,\,-3,\,0)}$ or $\phi_{(4,\,0,\,-3)}$, relative to wavelength. As a result, the AR at the user end can tolerate larger ionospheric errors.

Further discussion of the effects of residual tropospheric errors after correction through interpolation of the tropospheric biases in the DD phase measurements, the reader is referred to Zheng & Feng (2005), which presents results from an analysis of about 130,000 ZTD data points sampled from 129 IGS stations across Europe over a 90 day period. The results have confirmed the dependency of the interpolated ZTD errors on user-to-reference distance. For a network with maximum user-to-reference distance of 100 to 200km, the maximum standard deviation of the interpolated residual ZTD errors is between 10 to 17mm. This level of error can cause DD ranging errors of a few centimetres, which is considered normal for AR and centimetre-level positioning with ambiguity-fixed ionosphere-free observables at the user end.

In future station design scenarios it is necessary to consider the situation where both dual-frequency and triple-frequency receivers were used together over the longer term. One straightforward strategy is to double the inter-station distance when triple-frequency receivers are used with respect to the inter-station distance when dual-frequency receivers are used. In this deployment scheme, dual-frequency receiver stations located between the triple-frequency stations are considered to be a densification, or simply as temporary stations. A reasonable deployment strategy is similar to the cell design of a cellular network, where a hexagon pattern provides for equidistant stations, which are at the centre of each coverage area, as shown in Fig XX Feng and Li (2008a) For an inter-receiver distance of 2d=140km, the maximum base-user distance would be only 1.155d=81km for a triple-frequency network. When the inter-receiver distance is increased to about 2d=180km, the maximum base-user distance is about 103km. This maximum base-user distance can restrict the standard deviation of the interpolated residual ZTD to a level of 10mm or so. Doubling the inter-receiver distance leads to a reduction in the number of stations by a factor of 4. As a result, the number of triple-frequency stations needed to cover the inhabited part of Queensland would be reduced to 40 to 50 stations, which is much more affordable.

In actual reference station deployment scenarios, however, it is desirable to optimally select station locations from candidate sites in a specific area to satisfy given criteria for the network, such as inter-station distances. This research made the first attempt to design an optimal station deployment scheme based on a graph-theory tool to minimise the number of stations for a specific maximum base-user distance and user (geographical) distribution. In particular two different reference station placement problems were examined, namely location-oriented reference station placement problem and area-oriented reference station problem, referring to Tang et al (2007); Tang & Feng (2008), Tang (2009.

The location-oriented reference station placement problem is described as follows. Given a set of potential locations where reference stations can be set up and the locations of the users, the location-oriented reference station placement problem is to select reference station locations among the potential reference station locations such that the total number of reference stations is minimum subject to a constraint, that is, the maximal average distance between any user to three closest reference station does not exceed a parameter D_{max}. This maximum base-rover distance *constraint must be satisfied in order to guarantee the* accuracy of the positioning services. The area-oriented reference station placement problem is to find a reference placement such that a given service area is completely covered by the reference stations and the distance from any location on the area to the closest reference station does not exceed a parameter D_{max}. Based on the proposed heuristic algorithms for the reference station placement problems, a reference station placement software tool that can consider the characteristics of dual- and triple-frequency GNSS reference stations has been developed.

6. Concluding Remarks

The paper has given an overview of several technical developments within the CRCSI-funded research project "Delivering Precise Positioning Services in Regional Areas". The overall technical framework has been proposed so as to transition the current RTK services to support future larger scale coverage over an area such as Queensland or for the whole of Australia. The framework enables mixed use of different reference GNSS receiver types, dual- or triple-frequency, single or multiple systems, in order to provide RTK correction services to users equipped with any type of GNSS receiver. Data processing models and algorithms appropriate for triple-frequency GNSS signals were outlined, with the key performance improvement of using triple carrier signals being reliable AR without distance constraints. The core enabler for regional precise positioning services is the regional network-RTK data processing software platform, designed to generate improved tropospheric grid and ionospheric grid corrections to support centimetre-level positioning services. The server-based RTK software component is being developed to allow for user positioning computations at server nodes instead of on the user's device. This platform can support the implementation of RTK services for various user requirements. It has been identified that the key limiting factor for the implementation of a regional scale network-RTK will be the distance-dependence of the tropospheric errors in the DD phase measurements. A reference station deployment scheme with a doubling of the inter-station distances has been proposed based on the long-range TCAR capacity and predictability of the tropospheric errors across a few hundred kilometres.

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References

Chen W., Hu C., Chen Y., & Ding X. (2001), ***Rapid static and kinematic positioning with Hong Kong GPS active network***. ION-GPS 2001, 11-14 September, Salt Lake City, Utah, 346 – 352.

Cislowski G., & Higgins M. (2006), ***SunPOZ: Enabling centimetre accuracy GNSS applications in Queensland***, Paper 100, IGNSS 2006 Symposium on GPS/GNSS, 17-21 July, Gold Coast, Australia.

De Jonge P., Teunissen P., Jonkman N., & Joosten P. (2000), ***The distributional dependence of the range on triple frequency GPS ambiguity resolution***, ION-NTM, 26-28 January, Anaheim, California, 605-612.

Feng Y., & Rizos C. (2005), ***Three carrier approaches for future global, regional and local GNSS positioning services: Concepts and performance perspectives***, ION-GNSS 2005, 13-16 September, Long Beach, California, 2277-2787.

Feng Y., & Rizos C. (2009), ***Network-based geometry-free three carrier ambiguity resolution and phase bias calibration***, GPS Solutions, 13(1), 43-56

Feng Y., & Li B. (2008a), ***A benefit of multiple carrier GNSS signals: regional scale network-based RTK with doubled inter-station distances***, Journal of Spatial Sciences, 53(1), 135-147.

Feng, Y. (2008), ***GNSS three carrier ambiguity resolution using ionosphere-reduced virtual signals***, Journal of Geodesy, 82(12), 847-862.

Feng Y., & Li B. (2008b), ***Three carrier ambiguity resolution: Generalized problems, models, solutions and performance analysis with semi-generated triple frequency data***, ION-GNSS 2008, 16-19 September, 2831-2840.

Hein G., et al (2007), ***Envisioning a future GNSS system of systems, part 1***, Inside GNSS, Jan/Feb, 58-67.

Feng Y., & Li B. (2009), ***Wide area real time kinematic decimetre positioning with multiple carrier GNSS signals***, Science in China D Series, Earth Sciences (in print).

Forssell B., Martin-Neira M., & Harris R. (1997), ***Carrier phase ambiguity resolution in GNSS-2***, ION-GPS 1997, 16-19 September, Kansas City, Missouri, 1727-1736.

Han S., & Rizos C. (1999), ***The impact of two additional civilian GPS frequencies on ambiguity resolutions strategies***, ION Annual Technical Meeting, 28-30 June, Cambridge, MA, 315-321.

Hatch R., Jung J., Enge P., & Pervan B. (2000), ***Civilian GPS: The benefits of three frequencies***, GPS Solutions, 3(4), 1-9.

Hatch R. (2006), ***A new three-frequency, geometry-free technique for ambiguity resolution***, ION-GNSS 2006, 26-29 September, Fort Worth, Texas, 309-316.

Kim D., & Langley R. B. (2007), ***Long-range single-baseline RTK for complementing network-based RT***K, ION-GNSS 2007, 25-28 September, Fort Worth, Texas, 639-650.

Li B., Feng Y., & Shen Y.Z. (2009), ***Three carrier ambiguity resolution: Distance-independent performance demonstrated using semi-generated triple frequency GPS signals***, GPS Solutions, DOI 10.1007/s10291-009-0131-6.

Lim, S. & Rizos, C. (2008), ***A conceptual framework for server-based GNSS operations***, *Journal of GPS*, 7(2), 35-42.

Rizos C., & Han S. (2003), ***Reference station network based RTK systems - Concepts & progress***, Wuhan University Journal of Nature Sciences, 8(2B),566-574.

Tang M., Feng Y., Burnett L., Hayward R., & Raymond K. (2007), ***A reference station placement scheme in deployment of network real-time kinematic positioning systems***, IGNSS 2007, Paper 123, 4-6 December, Sydney, Australia.

Tang M. & Feng Y. (2008), ***Area-based reference station placement for network RTK***, in Proceedings of International Conference on Computer Science and Software Engineering (CSSE 2008), IEEE Computer Society Press, Wuhan, December, 2008, 919-922.

Tang M. (2009), ***QoS-aware reference station placement for regional network RTK***, Journal of Software Engineering and Applications, Vol.2, No.1, 2009, 44-49.

Teunissen P., Joosten P., & Tiberius C. (2002), ***A comparison of TCAR, CIR and LAMBDA GNSS ambiguity resolution***, ION-GPS 2002, 24-27 September, Portland, Oregon, 2799-2808.

Vollath U., Birnbach S., & Landau H. (1998), ***Analysis of three carrier ambiguity resolution (TCAR) technique for precise relative positioning in GNSS-2***, ION-GPS 1998, 15-18 September, Nashville, TN, 417-426.

Vollath U. (2004), ***The factorized multi-carrier ambiguity resolution (FAMCAR) approach for efficient carrier-phase ambiguity estimation,*** ION-GNSS 2004, 21-24 September, Long Beach, California, 2499-2508.

Zhang J., & Lachapelle G. (2001), ***Precise estimation of residual tropospheric delays using a regional GPS network for real-time kinematic applications***, Journal of Geodesy, 75, 255-266.

Zheng Y and Feng Y (2005) ***Interpolating Residual Zenith Tropospheric Delays for Improved Regional Area Differential GPS Positioning***, NAVIGATION, Journal of the Institute of Navigation, Vol 52 No 3, 2005, 179-187