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RTK Rover Performance using the Master-Auxiliary Concept

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Abstract. The Master-Auxiliary Concept, jointly proposed by Leica Geosystems and Geo++, is the basis of the soon to be released RTCM 3.0 network messages, the first industry standard for network RTK. The new standard, in addition to promoting increased compatibility and innovation in the industry, offers some distinct advantages to the end user over the previous generation of network corrections, such as VRS. With the Master-Auxiliary Concept complete information on the prevailing errors sources is made available to the rover, thereby facilitating the use of more intelligent positioning algorithms in the determination of the rover's position. The net result is an increased robustness of the system and increased performance in terms of time to fix, reliability of the ambiguity fix and position accuracy. Empirical data from both Leica and third party reference station software and rover receivers is used to demonstrate the real world benefits of the Master-Auxiliary Concept in general and the Leica solution in particular. Clear improvements can be seen when combining the Leica GPS Spider network RTK software with the Leica System 1200 GPS receivers, even when using network correction data at a sampling rate of only 5s.

Keywords. GPS, network RTK, standard, master-auxiliary concept

1 Introduction

The use of network RTK in GPS surveying offers several advantages over single base station positioning. For the rover user, the advantage of network RTK is that he can confidently operate at greater distances from the nearest reference station whilst maintaining a high reliability and accuracy. For the network operator, network RTK allows the same level of service to be provided with fewer reference stations. These benefits are achieved by using multiple reference stations spread over a region to observe the spatial distribution of the dominant error sources, namely ionospheric delay, tropospheric delay and orbit error. These errors, which may be classified as dispersive (ionosphere) and non-dispersive (troposphere and orbit) cause a distance-dependant bias in the position solution. With the additional information from the network, it is possible to reduce the distance-dependency thereby providing consistent rover performance across the network. During its infancy, several approaches to network RTK have been used, namely that of VRS and FKP. These approaches have numerous problems or limitations as described by Brown *et al*. (2005). Some of the key problems are:

1. The modelling performed by the network software, which is proprietary, greatly influences the information that is provided to the rover. Thus not all of the relevant information is provided to the rover prohibiting it from using the optimal processing techniques for the situation at hand.
2. Proprietary information is transmitted. As such the corrections formats are non-standard and are biased towards a particular brand of rovers. They are also contrary to the philosophy of industry standard from RTCM.
3. VRS requires a two-way data link, thus limiting the number of simultaneous users and preventing broadcast distribution of the corrections.

In order to address these and other limitations of the earlier approaches to network RTK corrections, Leica Geosystems has driven the development and adoption of the Master-Auxiliary Concept (MAC) within RTCM Special Committee 104. The following section gives an overview of the master-auxiliary concept and shows how it addresses the shortcomings of the earlier approaches mentioned above.

Brown *et al*. (2005) have shown that the master-auxiliary network messages offer higher reliability and accuracy than FKP, VRS and single baseline solutions in a direct comparison against existing solutions in the market. This paper expands on the results of Brown *et al.* (2005) to give a deeper insight into the master-auxiliary concept in general and the Leica GPS Spider solution in particular. Further analysis of the testing results is made in order to explain the difference in performance between the different approaches.

2 The Master-Auxiliary Concept

2.1 Background

In September 2001, Leica Geosystems together with Geo++ presented a paper titled "Study of a Simplified Approach in Utilizing Information from Permanent Reference Station Arrays" (Euler *et al.*, 2001) to the RTCM SC104. This paper contained a proposal for a standard for network correction messages that would overcome the problems of the existing approaches. Since 2001 Leica Geosystems has been a driving force behind the establishment of a standard for network RTK, which would be a benefit to the whole surveying industry. The master-auxiliary proposal put forward by Leica Geosystems and Geo++ has since undergone refinements based on input from other manufacturers. At the time of writing, the master-auxiliary network messages are the only fully documented non-proprietary proposal for network RTK messages under consideration by RTCM SC104 and have remained in their current form for over one year. Just as NTRIP was in use prior to its formal acceptance by RTCM as a standard, RTCM 3.0 network messages are already available with the Leica GPS Spider reference station software and the Leica System GPS 1200 products. Official acceptance and release of the standard is pending the completion of an interoperability test sanctioned by RTCM and currently in progress between the major manufacturers.

2.2 Concept Overview

The basic principle of the master-auxiliary concept is to provide, in compact form, as much of the information from the network and the errors it is observing to the rover as possible. With more information on the state and distribution of the dispersive and non-dispersive errors across the network, the rover is able to employ more intelligent algorithms in the determination of its position solution. Since each supplier of reference station software will have their own proprietary algorithms for modelling or estimating these error sources, to make a standard it is necessary to divide the computation into the following steps:

1. **Transmission of data to the network processing centre.** Raw code and phase data from each reference station is collected at a processing facility together with supporting information such as precise ephemeris, IONEX and DCB data.
2. **Network ambiguity resolution.** The phase ranges from all reference stations are reduced to a *common ambiguity level* (Euler *et al.*, 2001). Two reference stations are said to be on a common ambiguity level if the integer ambiguities for each phase range (satellite-receiver pair) have been removed (or adjusted) so that when double differences are formed the integer ambiguities cancel. In order to be able to resolve these network ambiguities, the reference station software must model or estimate all relevant error sources, such as satellite and receiver clocks, ionosphere, troposphere and orbit errors.
3. **Site selection.** A subset of the stations in the network is selected that will be used to generate the corrections for the rover. With two-way communications, this can be done by the reference station software, which can select the optimal set of sites that gives the best solution for the rover whilst minimising the amount of data to be transmitted. With broadcast communications the set of sites can be pre-defined by the network operator.
4. **Formation of the network messages.** The master-auxiliary *correction differences* are formed using the phase observations of the selected reference stations, corrected only by the estimated network ambiguities, the common part of the receiver clock and known values (geometric range and satellite clock). Thus, the messages are not influenced by proprietary modelling or estimation algorithms used by the network processing software in order to resolve the network ambiguities. A highly compact message format is used to minimise the bandwidth that is required to transmit the corrections (Euler *et al.*, 2001). To help reduce the amount of data to transmit, one of the reference stations assumes the role of the master station for which the full observations are transmitted. Between-station single differences are then used to create the correction differences that are transmitted for the other (auxiliary) stations. For convenience, the master station is usually chosen as the station closest to the rover. Note however that the distance of the master station to the rover has no bearing on the accuracy of the subsequent interpolation (step 6 below), since it plays no special role in the calculation.
5. **Transmission of the corrections.** The network messages are transmitted from the reference station software to the rover using any of a wide range of two-way or broadcast communication mediums.
6. **Localisation of the errors to the rover's position.** The rover uses the information provided by the

network to determine the dispersive and non-dispersive errors at its location. A typical approach is to use an interpolation algorithm, such as the Distance-Based Linear Interpolation Method (Gao *et al*., 1997; Dai *et al*., 2003; Euler *et al*., 2004), Low-Order Surface Model (Dai *et al*., 2003; Euler *et al*., 2004; Wanninger, 2000; Fotopoulos & Cannon, 2001) or Least-Squares Collocation Method (Raquet, 1998; Marel, 1998; Raquet and Lachapelle, 2001; Alves, 2004). Since this localisation is done on the rover, unlike with VRS, it is possible to broadcast the corrections.

7. **Determination of the rover's position.** The rover resolves its ambiguities and determines its position using the full information of the reference network.

By following this process it is possible to utilize the information provided by the network to full benefit whilst having a standard, open format and a process that is seamless for the rover user. Conceptually, the main difference between MAC and the other approaches is that it shifts some of the intelligence from the reference station software onto the rover. The practical advantages and implications of this shift are discussed in the following section.

3 Master-Auxiliary Concept in Practice

3.1 Optimal Site Selection

A reference station network may comprise between three and one thousand or more reference stations. Depending on the size of the network and the capacity of the supporting IT infrastructure it may be necessary to distribute the processing across two or more servers. In such a case the network may be divided into clusters. Each cluster contains a subset of the overall network, usually with some stations overlapping with adjacent clusters, and is processed as a single solution (Figure 1). Due to the broad geographical region typically covered by a cluster, not all of stations will be able to provide relevant correction information to a rover at any given location in or near the cluster. This is because the ionospheric and tropospheric errors that network RTK is trying to model are spatially correlated and so stations that are a long way from the rover (e.g. more than 50-100km depending on the location and characteristics of the network) will be influenced by substantially different atmospheric conditions. Hence, it does not make sense to use all stations in a network or cluster to generate corrections for the rover. For this reason, Leica GPS Spider uses the concept of cells. A cell is a subset of stations that is chosen based on certain criteria to be the optimal set of stations to provide MAC corrections to the rover.

The method of site selection for a cell that is used depends on the communication technology that is used. In the case of two-way communications, Leica GPS Spider will automatically select the optimum set of sites for the cell used to generate master-auxiliary corrections for each rover. This correction service is referred to as Auto-MAX. By choosing the most appropriate cell configuration, Auto-MAX corrections minimise the bandwidth required to transmit the corrections. The master station is always chosen as the station nearest to the rover. The auxiliaries are chosen from the surrounding stations to provide the best possible set of corrections for the rover's position. With Auto-MAX even the largest reference networks can be fully serviced with a single communication channel.

For broadcast communication mediums, pre-defined cells, which may be created manually by the network operator, can be used to transmit master-auxiliary corrections, known as MAX, to the rovers. The rover user can connect to the correction service that is most relevant for their geographic location. Depending on the size of the network, multiple cells can be defined to optimise the transmission of data by reducing the number of stations that are contained in the correction messages.

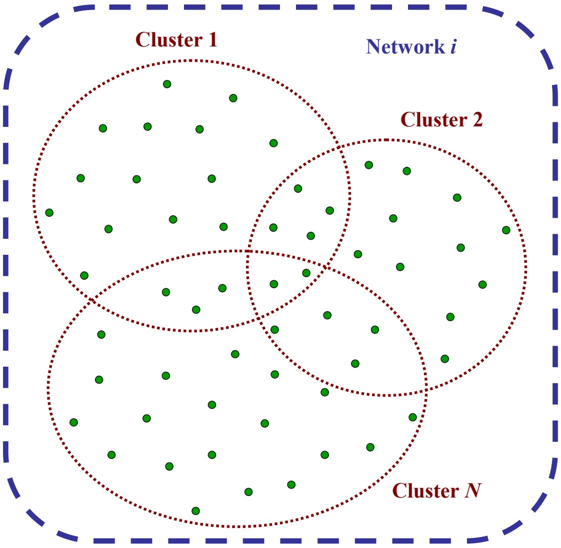

Figure 1. A reference station network comprising a number of clusters.

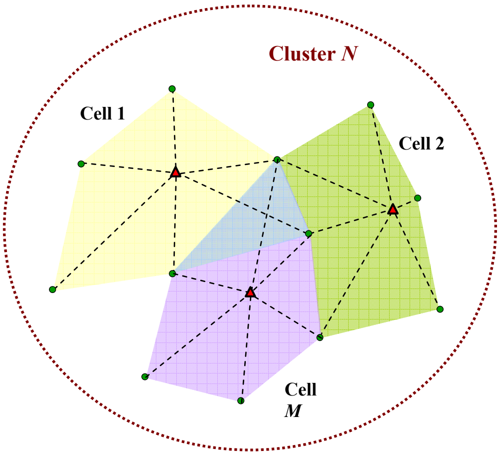

Figure 2. A cluster providing master-auxiliary corrections to several rovers, with each rover using an appropriate cell based on its location.

3.2 Rover Use of the Network Corrections

Since the corrections differences transmitted in the MAC network messages are ambiguity levelled, the rover is able to directly calculate the influence of the ionosphere, troposphere and orbit at its location. Hence, the rover does not need time for models or estimates of the errors to converge, unlike the network processing software (which must resolve the network ambiguities). The combined influence of the troposphere and orbit can be calculated for each satellite and each reference station using the ionosphere-free linear combination and then interpolated for the rover's position. Similarly, the influence of the ionosphere can be calculated for each satellite and each reference station using the geometry-free linear combination and then interpolated for the rover's position. Thus, high accuracy positioning is possible from the moment the first set of corrections is received.

3.3 Update Rate of the Network Corrections

Update rates of 1s are supported for both the master station observations and the dispersive and non-dispersive errors. Update rates for the dispersive and non-dispersive errors can be configured to be slower than 1s to conserve bandwidth. In the mid-latitudes, the rate of change of the differential ionosphere is usually less than a few millimetres per second and corrections should be updated at least at 10s (RTCM66, 2002). According to RTCM66 (2002), experience has shown that under normal operating conditions an update rate of 2-10s for the dispersive component is sufficient to achieve full accuracy at the rover. A lower rate of 10-30s may be used for the non-dispersive component, which changes more slowly (RTCM66, 2002). Therefore, having an update rate (of say 2s or 5s) for these corrections will not significantly impact on the accuracy of the rover's position. Table 1 shows the bandwidths that are required to transmit different corrections. Clearly, MAX corrections with a update rate of 1s for the master observations and 2s for both the dispersive and non-dispersive network messages uses a similar bandwidth to VRS even though it is transmitting considerably more information. Note that just because VRS is transmitting at 1s does not mean that the network corrections are being updated at that rate. If the network processing software must do the interpolation of the network data at 1s in addition to the network ambiguity resolution, file archiving and other tasks, it would run into performance problems when many rovers are connected. With MAC, the processing load is distributed between the reference station software and the rover and so is more efficient.

In the following sections a performance comparison is made between single baseline, MAX and other network correction formats. It should be noted that MAX used an update rate of 5s for the network corrections and still gave clearly superior performance to VRS and FKP.

Table 1. Bandwidths for network corrections.

Format	Number of Auxiliary Stations		
	6	8	10
VRS, RTCM 2.3 18/19, 1s update rate	3776bps#	3776bps#	3776bps#
i-MAX, RTCM 3.0 1004, 1s update rate	1391bps	1391bps	1391bps
MAX, RTCM 3.0 1017, 1s update rate for master and network corrections	5255bps	6567bps	7879bps
MAX, RTCM 3.0 1017, 1s update rate for master and 2s for network corrections	3287bps	3943bps	4599bps
MAX, RTCM 3.0 1017, 1s update rate for master and 5s for network corrections	2106bps	2368bps	2631bps

This value does not include the variable length type 59 proprietary information message, so the actual bandwidth may be higher.

3.4 Legacy Rover Support

The full observations for the master station are transmitted in the normal RTCM 3.0 1003/1004 message. Hence, a rover that is able to understand RTCM 3.0 but not the network corrections is still able to use the correction stream. For older rovers, Leica GPS Spider provides an individualised version of the master-auxiliary corrections, known as iMAX, that may be transmitted using older versions of RTCM. A performance comparison of iMAX with the other correction formats is given in the following section.

4 Performance Comparison

4.1 Test Setup

In order to assess how the advantages of the Master-Auxiliary Concept translate into benefits for the user, data was collected from Leica's RTK testbed. Figure 3 gives an overview of the network setup. The network consists of 5 stations in the border region between Switzerland, Austria and Germany. Each station is equipped with a dual-frequency GPS receiver and is permanently connected to the Leica office via a broad-band internet connection. German, Swiss and Austrian surveying authorities operate the stations. This network does not represent an unrealistic, idealized showcase network, but reflects rather challenging conditions: besides featuring a mix of different receiver and antenna makes and models, the reference station separations are up to almost 100km. Especially challenging is the height separation among the stations: the lowest station (Uznach) is at an elevation of 475m, whereas the station Kops is more than 1900m above sea level.

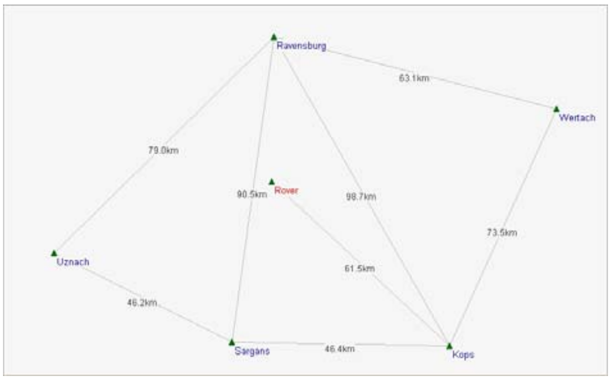

Figure 3. Overview of the test network.

Leica SpiderNet was used to calculate single site, MAX and iMAX corrections in RTCM 3.0. The MAX corrections were based on an update rate of 5s for the dispersive and non-dispersive components of the network corrections. A third-party network RTK software package was used to generate FKP and VRS corrections. All network corrections were based on the same five stations and were processed simultaneously. The single baseline corrections were taken from station Kops. The rover antenna was located at the Leica office at a height of 474m, where the five receivers in Table 2 were connected to the same rover antenna. The distance from the rover antenna to the closest reference station, Ravensburg, was 43 km. The distance to the master station Kops, which was deliberately chosen to be further away to show that the choice of the master station is not critical for the rover performance, was approximately 60km with a height difference of 1500m.

This test ran for several months allowing the first true long-term statistical analysis of rover performance when using Master-Auxiliary corrections. The following sections present typical results from a representative 16h time window of these long-term measurements.

Table 2. Overview of the receivers and correction formats that were used in the test.

Receiver	RTK Correction type	RTK Format
Leica GX1230 #1	Single baseline (Kops)	RTCM v.3.0
Leica GX1230 #2	i-MAX	RTCM v.3.0
Leica GX1230 #3	MAX	RTCM v.3.0
Leica GX1230 #4	FKP	RTCM v.2.3
Third-party receiver	VRS	RTCM v.2.3

4.2 Availability and Time to Fix

The productivity of a GPS field crew however depends mainly on the availability of fixed ambiguities (Richter and Green, 2004). Figure 4 summarizes the percentage of epochs with RTK fixed, differential code and navigation solutions that were achieved over the test period. MAX and iMAX show very similar values and show a better performance to other network RTK formats. The single baseline with a Leica rover is in terms of productivity on a similar level as MAX and iMAX, however in this case the field crew would of course not benefit from the gain in accuracy demonstrated in the following section.

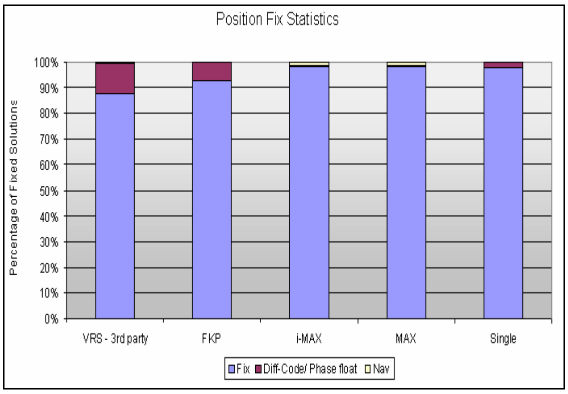

Figure 4. Percentage of fixed solutions.

The test and analysis presented so far simulated a rover occupying a point permanently for 16 hours without interruptions, and thus re-initialisations were only necessary in case of loss-of-locks or interruptions of the correction streams. To achieve results as realistic as possible, a further test was performed which forced the Leica receivers to continuously re-initialise (a full reset of the ambiguity filter) immediately after fixed ambiguities were attained. If no initialisation was achieved after three minutes, a new reset was forced. As the third-party rover did not allow an automated ambiguity reset, it was not included in this test.

Figure 5 includes both the number of RTK fixes within a certain time-to-fix interval, as well as the total number of ambiguities and confirmation of ambiguities. A higher number of restarts indicates a higher availability and reliability and is in fact the most important factor in terms of productivity gain.

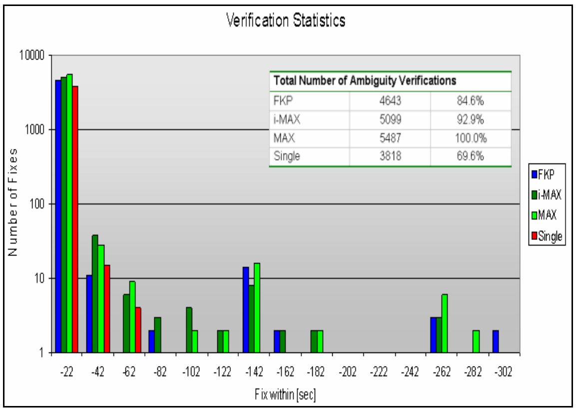

Figure 5. Time-to-fix (TTF) and ambiguity verification (logarithmic scale).

All three network RTK formats have a higher number of fixes within the first 22 seconds than the single baseline. The single baseline is close in this interval, however its overall number of fixes is significantly lower. If the ambiguities of the single baseline cannot be resolved in the first minute, the conditions are not improved by extending the search period due to significant atmospheric biases. In a few cases the network results can be improved by extending the search period, which proves that the corrected reference observations are more consistent and may enable ambiguity resolution in conditions where single baseline would not be possible.

Among the network RTK formats, MAX and iMAX perform at a similarly high level. FKP shows an almost equal percentage of fixes within 22 seconds, but has 15% fewer restarts.

4.3 Precision and Accuracy

One measure of RTK performance is to compare the accuracy of the measured RTK position with the ground truth. The NMEA GGA positions from each receiver listed in Table 2 were used to determine precision and accuracy estimates for the different network RTK formats. This paper will focus on analysis of the height component, since it is the most difficult component in GPS positioning. For a more detailed analysis of horizontal position results and for kinematic tests, the reader is referred to Brown *et al*. (2005). Figure 6 shows the height precision of a MAX solution compared to a single baseline. The results of the MAX data show noticeable benefits. In the 60km single baseline there are a significant number of outliers above 15 cm, but none when using the network solution. The network information for the troposphere and ionosphere also improves the precision of the height results.

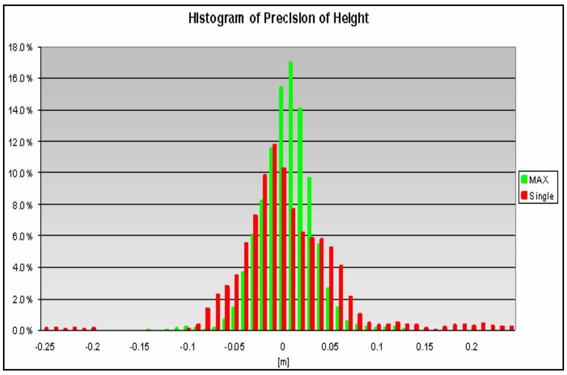

Figure 6. Height histogram from single baseline and MAX corrections

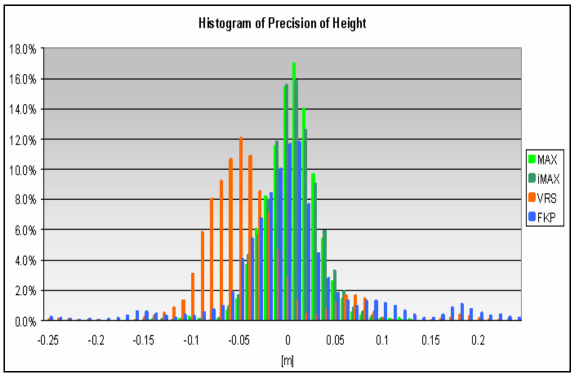

Figure 7. Height histogram from different network RTK corrections

However, differences can also be seen between different network RTK formats (Figure 7). As expected, MAX and i-MAX show very similar values. The VRS corrections, which were processed by the third-party receiver, show a significantly lower precision. In addition, a high number of wrong fixes caused a bias in the average height seen as a shift in Figure 7.

In order to demonstrate why MAX is able to give superior performance two periods of time (A and B) will be analyzed in more detail. Time period A covers approximately ninety minutes starting at 7:35am local time. Time period B also has a duration of approximately ninety minutes but starts at 9:35 pm local time, not long after sunset. The residual dispersive (ionosphere) and non-dispersive (troposphere and orbit) errors after double differencing and application of standard tropospheric (Modified Hopfield) and ionospheric (Klobuchar) models where calculated. Since for this test the rover and reference station coordinates were known is was possible to determine this error directly by removing the integer ambiguities. These residuals over time period A are shown in Figures 8 and 9 for the single baseline solution and in Figures 10 and 11 for the MAX solution. The residuals are displayed in units of L1 cycles.

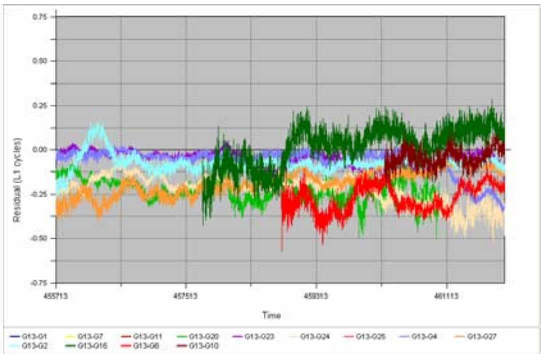

Figure 8. Double difference residual dispersive error for the single baseline solution during time period A.

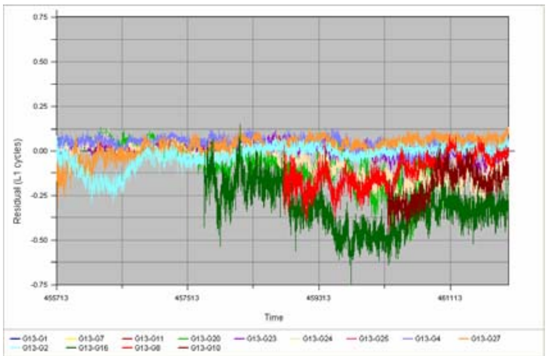

Figure 9. Double difference residual non-dispersive error for the single baseline solution during time period A.

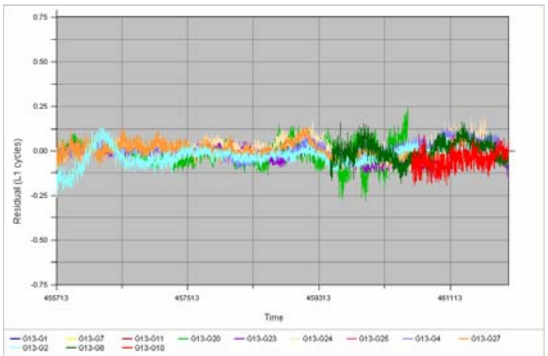

Figure 10. Double difference residual dispersive error for the MAX solution during time period A.

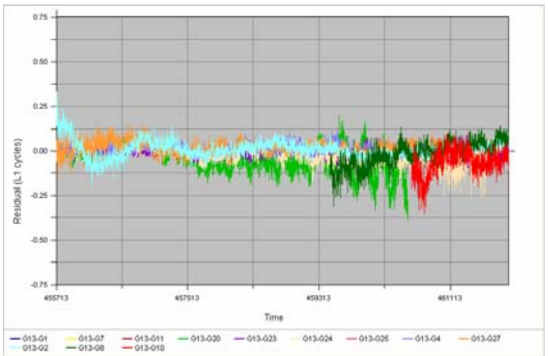

Figure 11. Double difference residual non-dispersive error for the MAX solution during time period A.

Both the dispersive and non-dispersive errors are reduced by the MAX corrections. Some residual error remains, notably on the double difference pair G13-G2 that could not be modeled. The low elevation (10 to 14 degrees) satellite G16 was not fixed by the network. The position results during this time are shown in Figures 12 and 13 as time series plots of the difference between the receiver's position solution and the known coordinate in easting, northing and height. The number of satellites used in the position solution is also displayed. Only RTK fixed positions have been plotted. For comparison Figures 14 and 15 show the results from VRS and FKP respectively. The single baseline solution was accurate around GPS second of week 457500 when it had some troubles fixing the ambiguities, indicated by the changing number of satellites used in the solution. No apparent reason for this can be seen in the residuals. All network solutions gave consistent performance over the entire period. The difference in the number of satellites used in the MAX and VRS/FKP solutions is due to the difference reference station software.

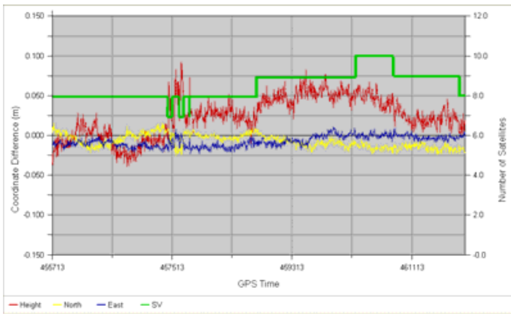

Figure 12. Difference from the known position for the single baseline solution during time period A.

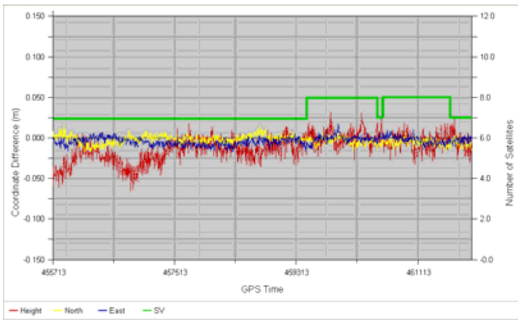

Figure 13. Difference from the known position for the MAX solution during time period A.

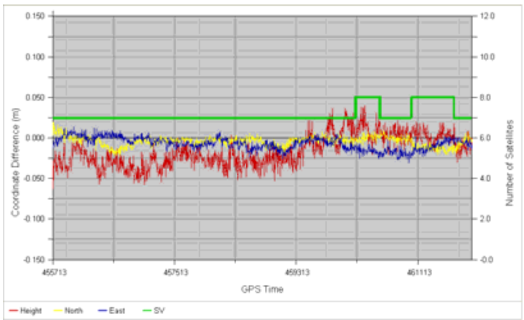

Figure 14. Difference from the known position for the VRS solution during time period A.

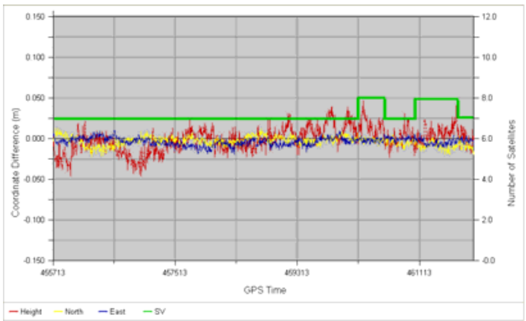

Figure 15. Difference from the known position for the FKP solution during time period A.

Note that the single baseline used consistently more satellites in its solution than any of the rovers using network corrections. This higher availability of satellites can, in some cases, enable the single baseline solution to match or even outperform a network solution.

The residual error graphs for time period B, over which the atmosphere is clearly more active, are shown in Figures 16 and 17 for the single baseline and Figures 18 and 19 for the MAX solution.

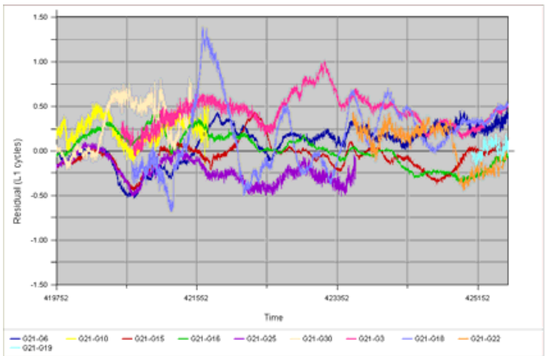

Figure 16. Double difference residual dispersive error for the single baseline solution during time period B.

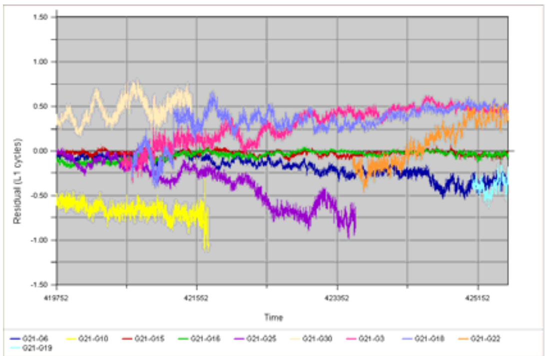

Figure 17. Double difference residual non-dispersive error for the single baseline solution during time period B.

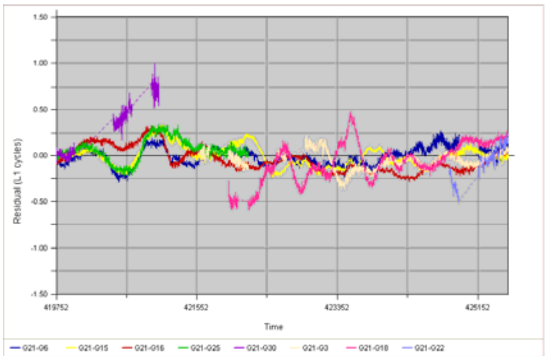

Figure 18. Double difference residual dispersive error for the MAX solution during time period B.

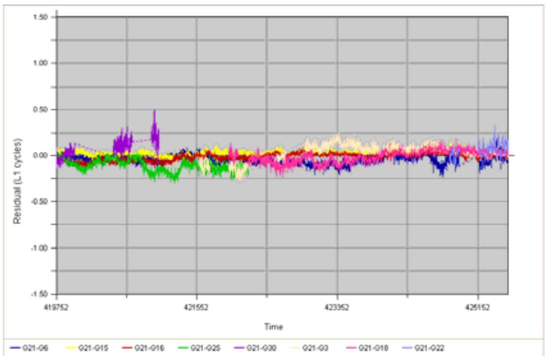

Figure 19. Double difference residual non-dispersive error for the MAX solution during time period B.

A much more significant improvement is seen in the reduction of the dispersive and non-dispersive errors by MAX during time period B. Some systematic dispersive error remains indicating that the ionospheric error was distinctly non-linear over the network. The network had difficulty maintaining the ambiguity fix for satellites G30 and G3. Satellite G18 was not fixed at all by the network during this time period. Thus this dataset represents a difficult situation for the network processing. Figures 20 through 23 show the accuracy of the rover's position over time period B for the single baseline, MAX, VRS and FKP solutions respectively.

As before, the single baseline uses overall more satellites in its solution than any of the network solutions. Interestingly the performance of the single baseline during time period B is similar to time period A in spite of the higher errors. The high ionospheric error is not seen in the position solution, which is based on the ionospheric-free linear combination for such long baselines. Surprisingly the single baseline solution was able to maintain a correct ambiguity fix over this time, which is a credit to the stochastic modeling and repeated search process used by the Leica rover (see Euler and Ziegler, 2000).

Whilst the MAX solution uses fewer satellites, the position solution is more accurate than that of the single baseline due to the reduced non-dispersive error. The VRS and FKP solutions also used fewer satellites than the single baseline, though slightly more than MAX. However, both the VRS and FKP solutions had difficulty over this period and actually gave lower accuracy than the single baseline. This is largely due to the fact that the VRS and FKP corrections are based on the error estimates from the state vector of the reference station software, rather than the actual error as used by MAX. In the case of VRS, the rover is tricked into thinking that the baseline is short so it did not use an ionospheric-free position solution, which would have removed the ionospheric error that could not be modeled by the corrections. Even though the MAX solution is using an update rate of only 5s for the network corrections (remember that the observations of the master station are always sent at a 1s rate), it clearly outperforms VRS and FKP.

These results also demonstrate, by the mix of reference station software and rovers that were used with the VRS and FKP solutions and the resulting poor performance, that one network solution is not the same as another. VRS and FKP use proprietary information that is not available to all rovers. By using an open standard such as the master-auxiliary concept based RTCM network messages, it is possible to make a level playing field by removing the manufacturer dependence and compatibility issues of the other approaches. With an open standard all rovers have an equal access to the correction data, thereby maximizing the benefit of the reference network for all users.

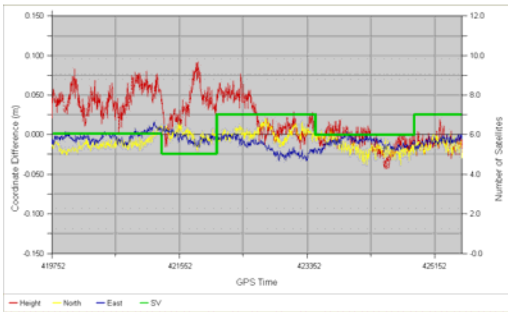

Figure 20. Difference from the known position for the single baseline solution during time period B.

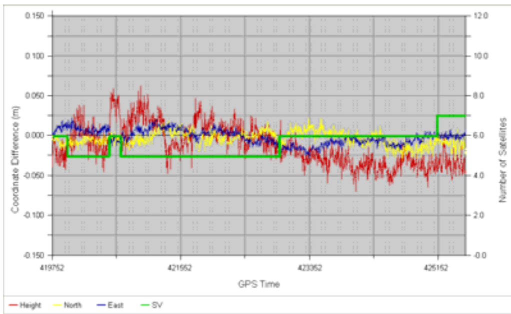

Figure 21. Difference from the known position for the MAX solution during time period B.

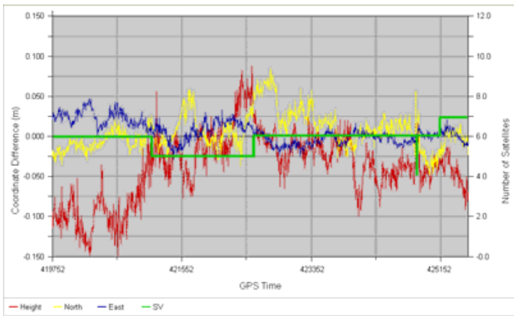

Figure 22. Difference from the known position for the VRS solution during time period B.

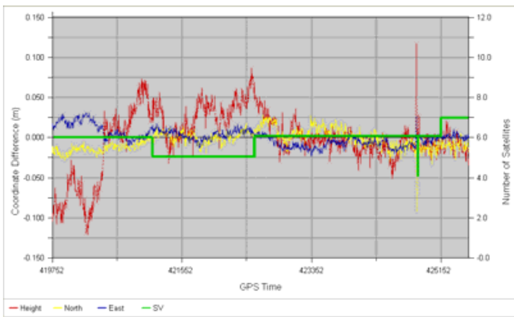

Figure 23. Difference from the known position for the FKP solution during time period B.

5 Conclusions

The Master-Auxiliary Concept, the basis for the forthcoming RTCM standard for network RTK corrections, is a revolutionary new approach to network RTK that addresses the limitations of earlier approaches. The MAC based RTCM network messages offer an open standardized format that enables efficient and accurate network RTK in both broadcast and two-way mode with out the need for proprietary messages and thus avoiding the compatibility issues of the earlier approaches. This paper has explained the principles and practical application of the Master-Auxiliary Concept. Empirical data was used to demonstrate the benefits of MAC for the rover user in terms of increased accuracy, performance and reliability, even though an update rate of only 5s was used for the network corrections. The statistical analysis of all tests clearly showed that the best performance was achieved by combining Leica GPS Spider with Leica GPS 1200 rovers utilizing MAX corrections. The individualized version of the MAX, known as iMAX, which is also available from the Leica GPS Spider reference station software gives a similar high level of performance as MAX but with the advantage of using a lower bandwidth single site RTCM 2.3 or 3.0 format that can also be interpreted by older receivers that do not support the new network messages.

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