System 1200 Newsletter – No. 54
RTK Networks – A Case Study

NETWORK RTK NEWSLETTERS – REFRESHER

This newsletter completes our three part series on RTK Networks. Before we continue with this it is an appropriate time for a refresher on the first two RTK Network Newsletters.

Newsletter 52 – An Introduction: This newsletter introduced the concept of RTK Networks, comparing their RTK method to the use of a Single Reference Station solution and provided the following conclusions:

- Money is saved by not needing to purchase a receiver as a reference station.
- By not setting up a reference station time and money can be saved on site and in the office.
- Using an RTK network work can be carried out over a large area without sacrificing quality (long baselines) or time (moving the reference station).

Newsletter 53 – Different Methods: This newsletter discussed different methods of Network RTK, Including:

Non-standardized methods; such as the individualized methods of i-MAX and Virtual Reference Station, where the rover sends an approximate position to the server, which then calculates the network solution and reduces the distance dependent errors;

MAC (Master Auxiliary Concept), the more advanced standardized method, where the network provides the rover with full raw observations and coordinate information for the Master station plus the ambiguity reduced observations and coordinate differences for the auxiliaries. The rover is then able to use all of this information to calculate an optimized RTK solution.

This newsletter also analyzed each method's advantages, disadvantages and performance in terms of traceability, repeatability and consistency, which highlighted the strengths of the MAC method. Leica Geosystems increases these strengths by using SmartRTK combined with 'MAX' (Leica's implementation of MAC).

If either of the two previous newsletters were missed or need to be viewed again; they (like all System1200 Newsletters) are available to download from the Leica Geosystems website: www.leica-geosystems.com.

NETWORK RTK WITH LEICA GEOSYSTEMS

RTK performance is maximized when Network RTK is carried out by a System1200 GNSS rover in a network run by Leica's GNSS Spider software. This high performance comes from using MAC/MAX and SmartRTK working with the powerful and precise System1200 receiver.

MAC/MAX & SMARTRTK

The terms MAC, MAX and SmartRTK are synonyms for world class GNSS network technology. Many readers will be familiar with these, but a short definition of each term may help users new to Network RTK:

- ***MAC***: stands for Master Auxiliary Concept, it is the most advanced and only internationally standardized Network RTK method. In the MAC method the rover is given all available information regarding the network stations and satellites and is then able to use its own intelligence to generate the best position fix.
- ***MAX***: is Leica's correction service which utilizes the MAC method. This setting that is available when using System1200 GNSS receivers and GNSS Spider Network software.
- ***SmartRTK***: is the RTK software running on the System1200 receivers which allows them to: intelligently combine raw & corrected satellite data to improve positioning accuracy by maximizing the use of all available data (Unified Position Solution); and optimize the combination of the L1 and L2 observations to provide a consistent solution which does not experience "jump" as solution methods are switched (Atmospheric Decorrelation).

It is when these three are used in conjunction i.e. A Spider GNSS network using the MAX setting to send MAC information to a SmartRTK enabled System1200 rover that network RTK delivers its best performance.

NETWORK RTK PERFORMANCE

All Network RTK methods offer benefits to the users such as the ability to work over a large area with minimal setup time and costs, but the degree of benefit the user experiences varies depending on the RTK Network method.

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SmartRTK used with the RTCM 3.1 standard MAC correction data brings added benefit to the user by utilizing the rover's intelligence to maximize the satellite data used, minimize errors and reduce residual biases. The two concepts that make this possible are 'Combining Network Information and Raw Observations' and 'Atmospheric Decorrelation'.

This high performance is best shown through the use of real data, as such, two case studies are presented:

1. Combining all available data to create a Unified Position Solution; 'Maximize the Data'.
2. Optimizing the combination of L1 and L2 data and ionospheric modeling using the SmartRTK Atmospheric Decorrelator; 'Feel the Atmosphere'.

Case Study 1: Maximize the Data

Combining Network Information and Raw Observations

In traditional network RTK solutions observations without corresponding network information are not processed. This means that a satellite needs to be tracked by all stations in the network as well as the rover in order to be used. As the inter-station distances in a network solution can be large, it is quite probable that when the rover is close to a reference station they may both be able to track satellites which other stations in the network are unable to.

SmartRTK approaches this situation differently and states that when handled properly combing raw and corrected observations (i.e. data from satellites which are seen by the whole network and ones which are not) is of benefit to the user.

As an example situation, a rover is in a network of 4 Stations, 3 of which are tracking only 5 satellites but the rover and closest reference are tracking 8 (Fig.1) there are two traditional rover solutions.

1. Use a network where only the satellites common to all stations would be used.
2. Use a single baseline solution where satellites seen by both the 'Master' station and rover would be used.

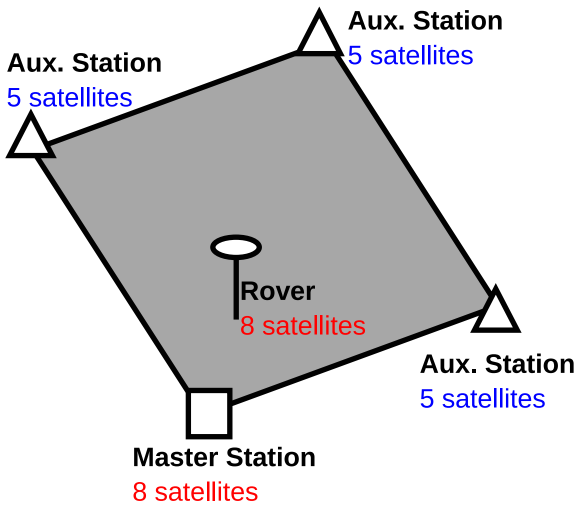

Figure 1: Network where the rover and Master are tracking more satellites than the auxiliary stations.

Solution 1 has traditional network advantages, distance dependent errors will be minimized and the Master to rover distance is not critical, but it will only use 5 satellites despite the rover actually being able to track significantly more.

Solution 2 will use 8 satellites but it is a single baseline RTK solution, so the distance between Master and rover is critical and errors would be seen as this distance increased.

SmartRTK uses a third option, a 'Unified Position Solution', where the 5 satellites tracked by the whole network are used in conjunction with the additional 3 satellites which are seen by both the rover and the Master (Fig. 2).

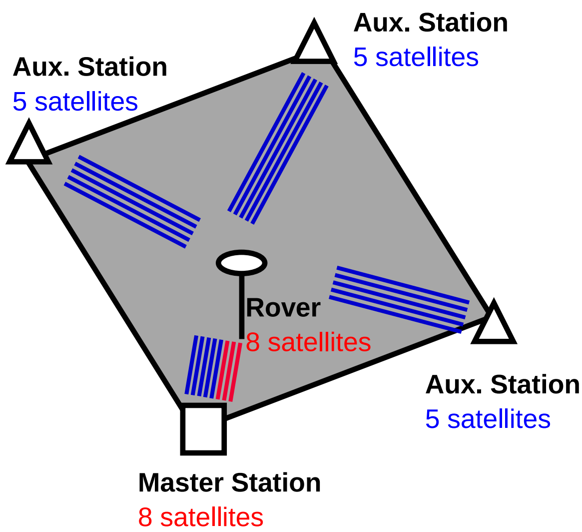

Figure 2: A SmartRTK solution using all possible Satellites to improve the data received by the rover.

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The potential benefits of using the SmartRTK solution with additional satellites are quicker initialization, improved accuracy and in some situations the ability to fix a position when a traditional network solution would be unable to.

THE NETWORK

This case study demonstrates the effects of this SmartRTK solution. Data was collected from a network (Fig. 3).

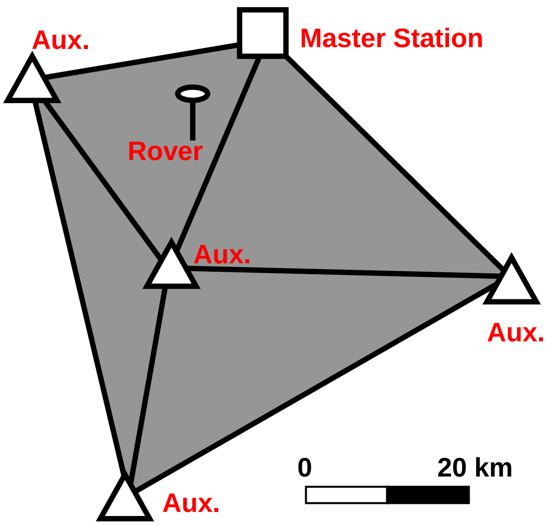

Figure 3: The network used in Case Study 1, the rover is approximately 15km from the master station.

The collected data from this network was processed three times using RTK models, as:

1. A single baseline from Master to rover.
2. A traditional network.
3. A network with SmartRTK processes.

As the data was collected over a period of time, the number of available satellites fluctuated during the session (Fig. 4).

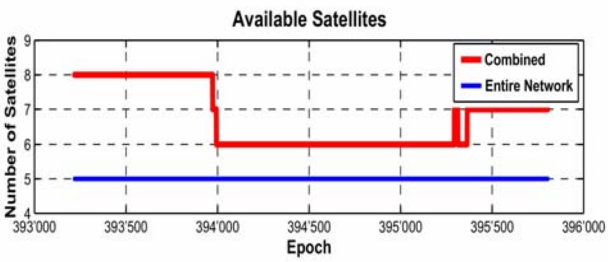

Figure 4: Available satellites for the rover & Master (combined) and the entire network.

During the plotted time period only 5 satellites were available for the entire network where as the number of satellites available for the Master and rover never fell below 6 and was as at 8 during the first quarter of the session.

HORIZONTAL POSITION

The first comparison of the different RTK methods for this data set is 2D horizontal position. Both the traditional and the SmartRTK network approaches have been independently compared to a single baseline solution (Fig. 5).

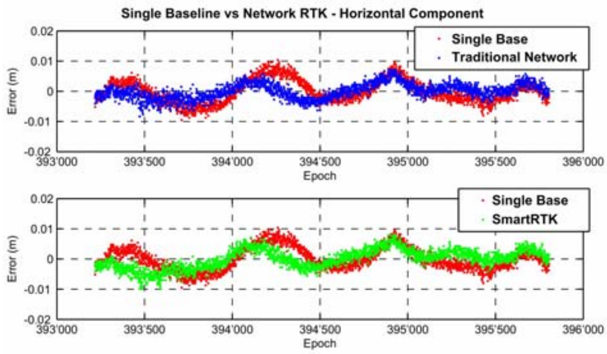

Figure 5: Horizontal position errors of the three RTK methods used on Case Study 1's data.

These graphs (Fig. 5) show that there is very little difference between using a network or single baseline solution in terms of horizontal position with this particular data set.

VERTICAL POSITION

In GNSS positioning the vertical component is typically 2 times less precise that the horizontal position. This is due to all of the observed satellites being above the horizon; as such the vertical performance of the various RTK methods has to be assessed (Fig. 6 & Fig. 7).

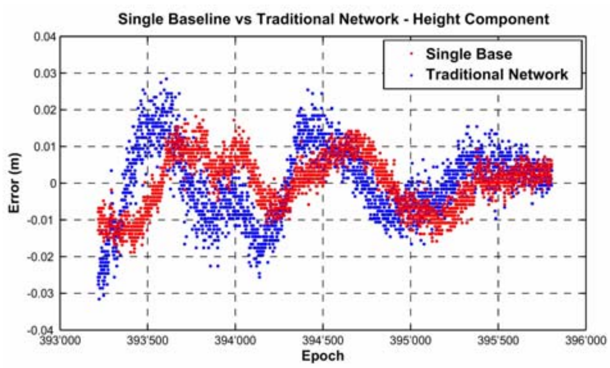

Figure 6: Vertical positional error of traditional network RTK against a single baseline solution.

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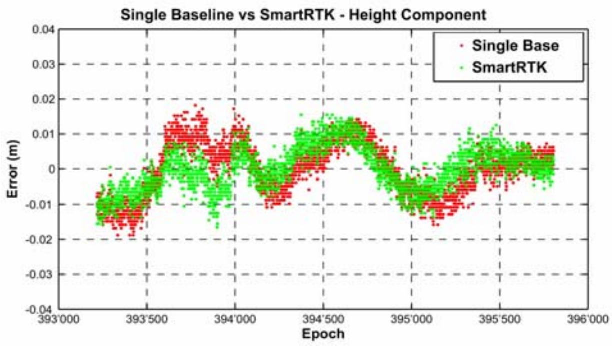

Figure 7: Vertical positional error of SmartRTK against a single baseline solution.

The data in the graphs (Fig. 6 & Fig. 7) show that despite the strong horizontal position the traditional network solution is not able to perform to the same level as single baseline and SmartRTK solutions in vertical position. Inspecting the results of figure 7 shows that SmartRTK delivers the best results. It has a lower standard deviation (0.006) than the single baseline solution (0.007) or traditional network approach (0.010).

Figure 4 showed that the network RTK solution was limited to only 5 satellites during the entire session; it is this limitation which has restricted the vertical position by forcing the rover to use weak satellite geometry (a high VDOP). The single baseline solution performs better than the traditional network, due to the use of extra satellites providing an improved geometry.

In this case the SmartRTK provides the best solution as it uses all the available satellites and the strength of a network. SmartRTK benefits from the strengths of both techniques in one.

Satellite Coverage

After the initial time period the number of available satellites for the entire network dropped below 5, during this time the rover and Master were still tracking at least 6 satellites. The drop in satellites can be seen in the calculated positions of the traditional RTK network (Fig. 8).

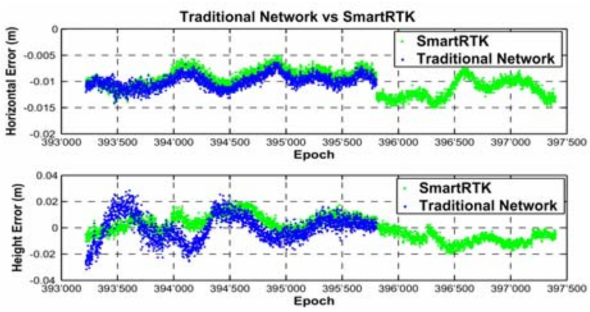

Figure 8: Horizontal and Vertical positional errors of SmartRTK against a traditional network solution.

The graph (Fig. 8) shows that after epoch 395805 the traditional network solution no longer has a fixed position, yet the SmartRTK method continues to calculate an accurate 3D solution.

As shown in the vertical position comparison ignoring the satellites not simultaneously tracked by the entire network limits the performance of traditional RTK methods, this becomes even more evident when the number of satellites tracked by the whole network falls below 5 and the fixed position is lost.

Summary

The data presented in Case Study 1 is a practical example of the benefits to a rover of using SmartRTK and its unified position solution.

Using this data it was evident that a SmartRTK method could provide a fixed solution where a traditional network RTK method would not and even when both solutions are working SmartRTK can provide better accuracy if additional satellites are available.

Typically, SmartRTK will use of 1-3 additional satellites in the position solution when the rover is in the vicinity of the Master station and MAC corrections are sent from the network.

Case Study 2: Feel the Atmosphere

Atmospheric Decorrelation

In order to achieve high accuracy RTK GNSS, positioning errors need to be understood, modeled and minimized. Typically, as the reference to rover distance increases, residual errors also increase. These distance dependent errors need to be modeled in order to be removed. However, imperfect modeling of these can cause residual bias.

It is well known that the magnitude of errors induced by the Earth's atmosphere, such as the troposphere and ionosphere, grows as the distance to the reference station increases. The tropospheric error is usually mitigated using empirical models such as Sasstamoinen or Hopfield. The ionospheric delay can be effectively minimized by forming a ionosphere-free linear combination of the L1 and L2 observables, commonly referred to as L3. However, the L3 observable is approximately 3 times less precise than L1 or L2 and should only be used when the ionospheric errors become significant.

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The conventional approach is to switch to an L3 solution at a pre-defined baseline length (Fig. 9). This approach has proven to be effective for conventional (single baseline) RTK.

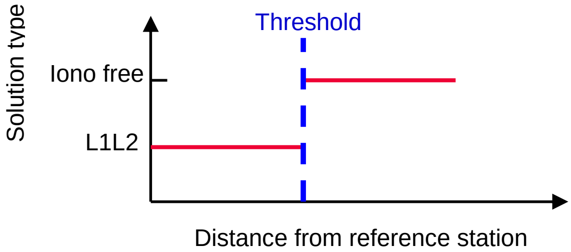

Figure 9: Representation of the solution type switch from L1/L2 to Iono free, L3, at a threshold distance.

The distance threshold for the switch of solution type can vary slightly from one manufacturer to another, such values were determined empirically using a large number of datasets, however, the results from the datasets used to calculate the threshold were combined to give a most suitable solution for the majority of cases. As a result the threshold may not give the ideal solution for the current atmospheric conditions.

In the case of network RTK, the distance dependent tropospheric and ionospheric errors at the rover are modeled by the network software. As a result, it is the quality of the atmospheric modeling rather than baseline length that governs the magnitude of the residual errors. Therefore, a more realistic approach to assess the quality of the observations is required in network RTK in order to optimally combine L1 and L2 observations.

SmartRTK adopts a different principle to the problem. It continuously monitors the residual atmospheric errors at the rover. It uses this information to optimally combine and weight the L1 and L2 observations to deliver a homogeneous position solution as the rover moves throughout the network; thereby utilizing the most suitable combination and avoiding the negative effects of an arbitrary 'hard switch' as seen with traditional approaches.

THE NETWORK

This case study demonstrates the effects of this SmartRTK atmospheric decorrelation. Data was collected from a network, where the rover was closer (just over 20km) to an auxiliary station than the master station (over 40km) (Fig. 10).

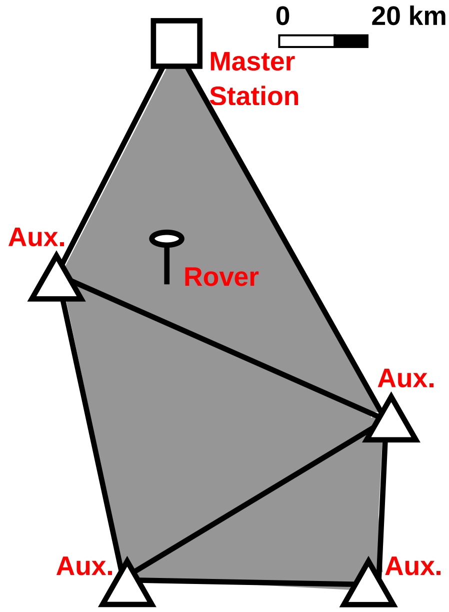

Figure 10: The network used in Case Study 2, the rover is approximately 43km from the master station.

Like the first case study, data was collected from the network and processed three times, as a single baseline, a traditional RTK network and a network with SmartRTK processes.

SINGLE BASELINE V TRADITIONAL NET RTK

The first test of this case study was to determine the potential benefits of using a traditional network RTK approach over a single baseline. Both the horizontal and vertical errors have been compared (Fig. 11).

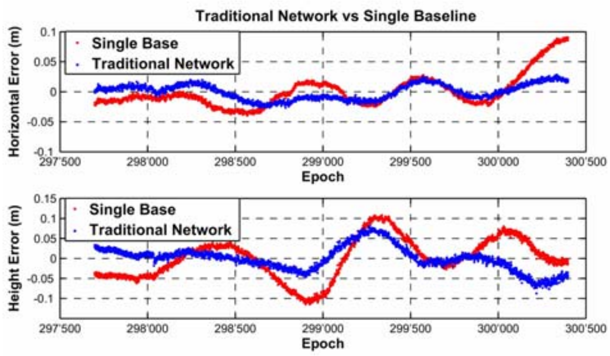

Figure 11: Horizontal and Vertical errors of a traditional network against a single baseline solution.

Figure 11 shows the single baseline performing worse than in case study 1 (due to the longer baselines), where positional errors remained under 10mm, in this case the single baseline has some positional errors as large as 90mm indicating that significant distance dependant residual errors are influencing the solution.

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The network solution performs better than the single baseline, but the positional errors are still significantly larger than in the first case study. Using the network solution is beneficial. However, it is evident that the residual errors influencing the single baseline are also causing residual bias in the traditional network approach.

SMARTRTK V TRADITIONAL NETWORK

Although a network solution is beneficial, errors still exist that could be reduced - this is where SmartRTK uses its atmospheric decorrelator.

SmartRTK treats residual distance dependent errors using optimal combinations of the L1 and L2 observables and ionospheric residual stochastic modelling, so it is be able to better handle the errors and reduce their influence.

The second test of this case study was to compare SmartRTK and its atmospheric decorrelator to the traditional network RTK (Fig. 12).

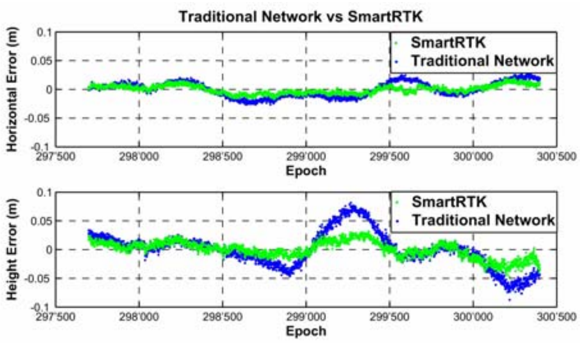

Figure 12: Horizontal and Vertical positional errors of SmartRTK against a traditional network solution.

The graphs (Fig. 12) visibly show that the SmartRTK solution is more precise than the traditional network. The large positional errors seen in the single baseline and traditional network between epochs 298,500 and 299,500 are successfully handled by SmartRTK's atmospheric decorrelator.

SUMMARY

SmartRTK produces much better results from this second case study than either of the other two methods. This is due to the handling of the distance dependant residual errors.

The case study is a practical proof, with real data, of the benefits to a rover of using Leica's SmartRTK and its atmospheric decorrelator. SmartRTK is able to produce more homogeneous position accuracy throughout a network even in disturbed atmospheric conditions.

REMEMBER

- Using SmartRTK and MAC corrections utilizes more data than any other RTK solution.
- The additional information used by SmartRTK and MAC provides a more traceable, reliable and consistent solution with distance dependent errors minimized and high precision.
- Even in a RTK Network not utilizing MAC corrections the atmospheric decorrelator will continue to function and a System1200 will provide the best performance within the network's limitations.
- SmartRTK is available on all System1200 receivers with firmware 5.50 or higher, for advice on how to check your firmware version and upgrading please contact your local Leica technical representative.
- RTK Networks are constantly being established in an increasing number of countries – to find out if an RTK Network is in your area, please contact your local Leica sales representative.
- More information on RTK Networks can be found on:

  http://www.leica-geosystems.com/corporate/en/products/gps_systems/lgs_4229.htm

NEXT TIME…

The next newsletter will look in detail at how Survey data can be exported from Leica Geosystems instruments and software to be imported and displayed within Google Earth™.

Please contact your local Leica representative if there are specific topics you would like to see covered in these newsletters.

We welcome all suggestions for TPS1200, GPS1200, specific applications or LGO. We look forward to receiving your ideas.