System 1200 Newsletter – No. 53
RTK Networks – Different Methods

RTK NETWORKS – DIFFERENT METHODS

The previous Newsletter (No. 52) focussed on the economic advantages of using a RTK Network as an alternative to setting up your own reference station.

This Newsletter focuses on evaluating four different Network RTK methods, MAX, i-MAX, FKP and Virtual Reference Station. There are significant differences between these methods and therefore different quality RTK solutions are achieved.

In the previous Newsletter we described the role of a Network RTK server – to collect satellite observations from many reference stations and send RTK corrections to the rover (Fig. 1).

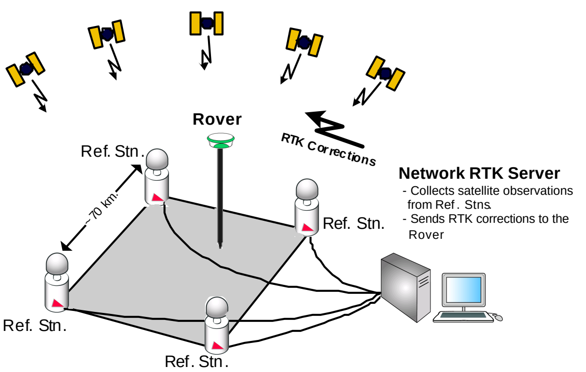

Figure 1: The role of the Network RTK Server

A Network RTK Service Provider, who sells user subscriptions, manages the Network RTK server. The Service Provider chooses the Network RTK method the server will use. Therefore, this choice will ultimately influence the quality of RTK solution that can be achieved at the rover.

This Newsletter identifies MAX (as based on the only standard for network RTK, RTCM V3.1 Master Auxiliary Concept - MAC) as the best Network RTK method available in the market today and explains why a user should request MAX corrections from their Network RTK Service Provider.

The next Newsletter (No. 54) will analyze real data to show that by combining MAX and SmartRTK (released in SmartWorx version 5.5 September 2007) a user has the best RTK solution available in the market.

HOW DO I EVALUATE A NETWORK RTK METHOD?

We described in the previous Newsletter that once the Network RTK server has received all the reference station observations it reduces them to a so called “common ambiguity level”. The algorithms that do this are specific to the Network RTK server software being used (e.g. **Leica GNSS Spider**).

Once a common ambiguity level is found, the server software employs a Network RTK method (e.g. MAX) to produce the RTK corrections for the rover.

All Network RTK methods have the advantage of reducing the distance dependent errors and therefore allowing large baseline lengths between the reference stations and the rover. However, each method achieves this in different ways.

To evaluate these different Network RTK methods let us define some criteria.

STANDARDIZED METHODS

Network RTK methods can be categorized as either standardized or non-standardized.

A standardized method is a method where the server software uses internationally standardized algorithms to generate Network RTK corrections. These algorithms have been published and are available to the public. This provides consistency and transparency for everyone who uses it.

A standardized method means that all information provided to rovers, regardless of manufacturer, follows clearly defined international standards.

A non-standardized method is a method where the server software uses unpublished algorithms to generate Network RTK corrections.

ROVER-CONTROLLED NETWORK SOLUTION

The aim of Network RTK is to reduce the distance dependent errors in the RTK solution – to optimize the solution and to improve initialization speeds over large distances between the rover and reference stations.

Depending on the method, either the server or the rover controls the calculation of the network solution to reduce the distance dependent errors.

- when it has to be **right**
Leica Geosystems

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A rover-controlled network solution is achieved when the rover can control which reference stations are used in the solution, how many reference stations, and which strategy is used to reduce distance dependent errors.

The advantage of a rover-controlled network solution is that the rover can continually evaluate the quality of its RTK solution and monitor the effectiveness of the distance dependent error corrections it is calculating. If the rover determines that the RTK solution is no longer optimized (e.g. due to a change in atmospheric conditions), then the rover can make an on-the-fly decision and change to a different strategy and calculate a network solution that is more appropriate – therefore maintaining initialization and an optimal RTK solution.

When the server controls the network solution, the server typically uses one strategy for all rovers – optimizing for the network, not for the individual rover. The server does not know how each rover is performing. Therefore, if the network solution is not appropriate for the rover's situation, the RTK solution might not be optimized and ultimately fast initialization may not be gained.

To ensure fast initialization and an optimized RTK solution, the **rover should control the RTK solution**.

MAXIMIZE USE OF ALL SATELLITE DATA

Network RTK servers collect satellite data from all the reference stations and generate RTK corrections to send to the rover. However, some methods do not maximise the full use of this data. In certain circumstances, this might mean the difference between being able to calculate an RTK solution or not.

For example, imagine a surveyor is in the field observing 8 satellites at their rover. They expect their rover to be able to quickly initialize. However, one of the reference stations being used to generate the RTK corrections is only observing 5 of the same satellites (as the rover). In this case, some Network RTK methods can only generate RTK corrections for the 5 common satellites or must drop one reference station from the solution and therefore weakening the solution. The rover may not receive enough data to initialize quickly and the surveyor is left waiting in the field.

The surveyor might have the best rover on the market, but its performance is being limited by the RTK corrections it is receiving. This is rather like buying the latest high definition TV to watch old VHS videos.

To maximise the rover's ability to calculate a RTK solution, the Network RTK method needs to **maximise the use of all the available satellite data**.

TRACEABILITY AND REPEATABILITY

Traceability is a common survey principle adopted by many surveying authorities around the world. This typically means that all measurements are legally required to be related to physical monuments. These measurements should also be able to be directly re-measured.

For example, a single baseline (dX, dY, dZ) between a reference station and a survey mark should be able to be repeated. This requires physical monuments (e.g. a pillar or peg), and therefore means the measurement is traceable.

Hence, any baselines generated from Network RTK should be **traceable** and **repeatable**.

CONSISTENCY

With single reference RTK the position accuracy decreases with distance from the reference station. With Network RTK this effect is reduced. The position and its accuracy should therefore be more consistent (homogeneous) throughout a survey (of course normal good practice guidelines for GNSS surveying, such as satellite availability and DOP values, also apply for network RTK).

A user does not want the position and accuracy to be jumping around. Therefore, positions and accuracies from Network RTK should be **consistent**.

Before going into detail on the different methods of Network RTK, let's focus on the relationship between the Network RTK server and the rover. This relationship is the major point of difference between the Network RTK methods.

THE NETWORK AND ROVER RELATIONSHIP

Why is this relationship important? Well, as you read through this Newsletter keep in mind the five criteria stated above.

To help describe why this relationship is important, let's define four basic parts (Fig. 2):

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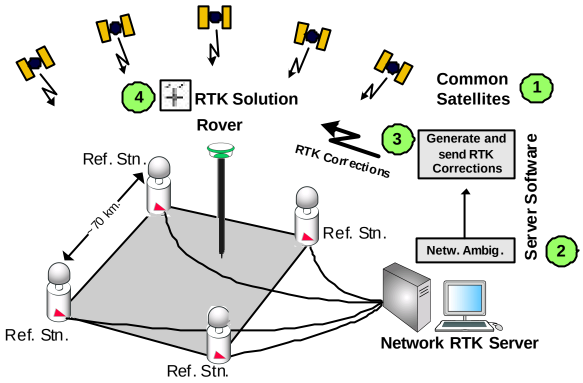

Figure 2: Four basic parts of the relationship b etween the server and the rover in Network RTK

1. **Observing Common Satellites:** The rover and the network server (through the reference stations) are observing a common set of satellites.
2. **Resolving Network Ambiguities:** Using an appropriate algorithm, the network server resolves the ambiguities of the network and reduces the satellite data to this common ambiguity.
3. **Generating RTK Corrections:** The server generates and sends the RTK corrections to the rover in either a standard or non-standard (ambiguous) representation.
4. **RTK Solution:** The rover uses the RTK corrections to compute an RTK solution.

WHY ARE THESE FOUR PARTS IMPORTANT?

These four parts are important as they help us understand how each of the methods differ and more importantly it helps us evaluate them.

The **RTK solution** is the most important part to the user. A user wants the solution to be reliable, accurate, consistent, traceable and repeatable.

The goal of the rover is to meet all of these criteria for the user. However, whether or not the rover can achieve this goal is dependent on the **RTK corrections** it receives from the server, which in turn are dependent on the method being used by the server.

The **common satellites** define the satellite observation dataset that is available. As previously described, how much of this dataset is represented by the RTK corrections can mean the difference between achieving an RTK solution or not.

INTRODUCING THE FOUR DIFFERENT METHODS

The MAX Method
The transmission of Master Auxiliary Corrections (MAX) is based on the Master Auxiliary Concept (MAC) proposed by Leica and Geo++ in 2001 (Euler et al., 2001).

The i-MAX Method
Individualized MAX (i-MAX) was developed at the same time as MAX to support older receivers that cannot support the MAX corrections.

The FKP Method
The Flächen-Korrektur Parameter (FKP, area correction parameters) method is the oldest Network RTK method and was developed by Geo++ in the mid 1990s.

The Virtual Reference Station Method
Terrasat developed the Virtual Reference Station method in the late 1990s and is comparable to i-MAX.

I-MAX AND VIRTUAL REFERENCE STATION

THE METHOD

The methods of i-MAX and Virtual Reference Station are similar. Both are classed as individualized that require the rover to send an approximate position to the server. The relationship between the server and the rover for i-MAX and Virtual Reference Station are shown in Figures 3 and 4 respectively.

Non-standardized methods
Both methods use unpublished algorithms to generate Network RTK corrections and are therefore non-standardized.

Server-controlled network solution
In both methods the server calculates the network solution to reduce the distance dependent errors. This means the network solution is not optimized for the rover's position and might be limiting the RTK solution.

Use of all satellite data NOT maximised
Both methods generate RTK corrections that simulate single reference RTK. This lmits the satellite data made available to the rover, therefore risking that in certain circumstances an RTK solution will not be possible.

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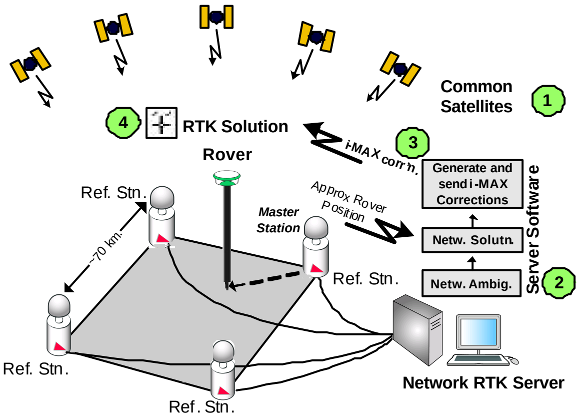

Figure 3: The relationship between the server and rover using the i-MAX method

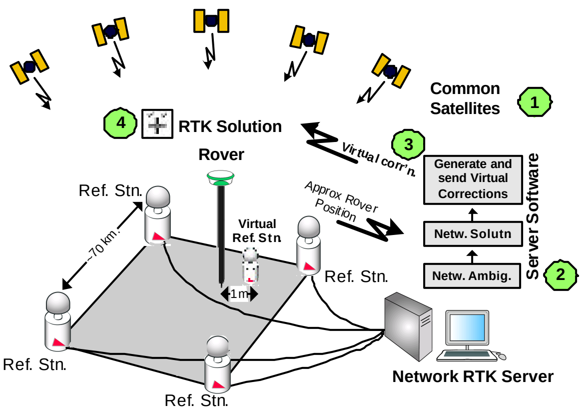

Figure 4: The relationship between the server and rover using the Virtual Reference Station method

POINT OF DIFFERENCE

The i-MAX and Virtual Reference Station methods are similar, but not identical. The major point of difference is that the i-MAX method generates corrections for a *real* reference station instead of a *virtual* reference station.

Traceability and Repeatability

The i-MAX corrections are related back to a master station. This means that the baseline between the master station and the measured point can always be directly re-measured. Therefore, the measurements are traceable and repeatable (Fig 3).

With the Virtual Reference Station method the rover does not receive any observations related to a real reference station. This means that the baseline between the virtual reference station and the measured point *cannot* be drectly re-measured. This violates the fundamental surveying principles of traceability and repeatability (Fig 4).

Consistency

The Virtual Reference Station corrections are optimised for the rover position at the beginning of the RTK session (i.e. after connecting to the Network RTK service). If the rover then moves a considerable distance within the same session (i.e. without disconnecting and reconnecting) the corrections might not be appropriate for the new rover location (Landau et al., 2003).

To resolve this issue, the user can disconnect and start a new session to generate a new reference station, or the server may automatically generate a new reference station. However, (in either case) generating new reference stations can cause jumps in position and accuracy. Therefore, the user can end up with inconsistent positions and accuracies throughout their survey.

In contrast, the i-MAX corrections are dynamically updated to follow the movement of the rover. In addition, i-MAX corrections are related back to a real reference station (the master station). This means that the resulting positions and accuracies are consistent.

AREA CORRECTION PARAMETERS (FKP)

THE METHOD

The FKP method is a broadcast method and does not require the RTK rover to send its current position to the network central server. Instead, the server models the distance dependant errors and sends RTK data from one reference station within the network to the rover, along with the model (Wübbena et al., 2001).

The FKP method creates area corrections parameters represented as simple planes (East-West and North-South gradients) that are valid for a limited area around a single reference station.

The relationship between the server and the rover for the FKP method is shown in Figure 5.

Non-standardized method

The method uses unpublished algorithms to generate Network RTK corrections and is therefore non-standardized.

Server-controlled network solution

In this method the server calculates the network solution (area correction parameters) to reduce the distance dependent errors. This means the network solution is not optimized for the rover's position and might be limiting the RTK solution.

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Typically the correction parameters calculated at the server are based on the assumption that the distance dependent errors change linearly between reference stations. However, interpolation errors will occur at the rover if the true errors are non-linear. This can result in poor position quality or problems in the ambiguity fixing.

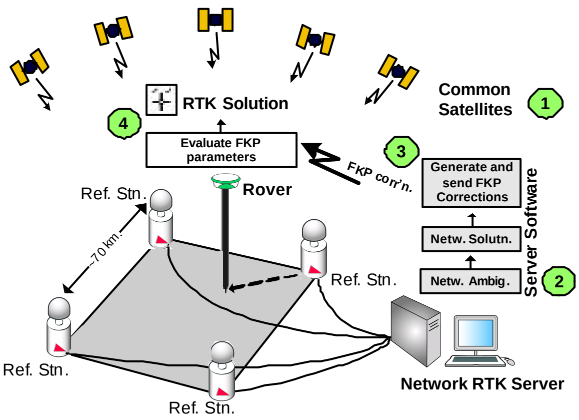

Figure 5: The relationship between the server and rover using the FKP method

Maximizes the use of all satellite data?

The FKP method sends all data from on reference station, however the area correction parameters have the same limitations as for Virtual Reference Station and i-MAX. Since the method is non-standardized, we cannot be sure if FKP maximises the use of all satellite data or not.

Traceable and Repeatable

The RTK corrections are related back to a real reference station and are therefore traceable and repeatable (Fig 5).

Consistency

The rover evaluates the area correction parameters at its current position to generate corrections. Combining these corrections with the RTK data from one of the reference stations, consistent RTK solutions (positions and accuracies) can be computed – provided that the rover does not move far from the reference station that the FTP parameters are linked to.

MAX Corrections

The Method

In the Master Auxiliary Concept the Network RTK server sends full raw observations and coordinate information for a single reference station, the Master Station. For all other stations in the network (or a suitable subset of stations), known as auxiliary stations, their ambiguity reduced observations and coordinate differences (to the Master Station observations and coordinates) are transmitted.

The relationship between the server and the rover is shown in Figure 6.

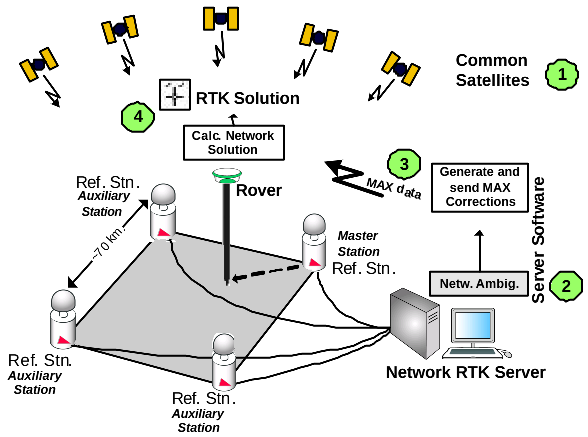

Figure 6: The relationship between the server and rover using the MAX method

Standardized method

MAX uses published algorithms to generate and send Network RTK corrections and is therefore a standardized method. In addition, the data is always traceable to real reference stations.

The RTCM Special Committee 104 has acknowledged this by making MAX the only official standard for Network RTK by including it in the RTCM 3.1 standards document.

Rover-controlled Network solution

The Master Auxiliary Concept gives the rover the flexibility to perform either a simple interpolation of the network corrections like FKP, or a more rigorous calculation (e.g. calculate multiple baselines from the auxiliary reference stations). This means the rover can monitor the RTK solution and change its calculation on-the-fly to optimize the RTK solution. This is a major advantage over FKP and any other method.

Maximizes use of all satellite data

With these MAX data the rover can reconstruct the ambiguity-reduced data of every reference station. Therefore, maximizing the use of **all** satellite data to calculate the best possible RTK solution.

Consistency

The rover has the possibility to adapt to the prevailing atmospheric conditions by using an appropriate number of reference stations (e.g. to model larger scale atmospheric activity). This means the rover can ensure that the RTK solutions (positions and accuracies) are consistent throughout a survey.

Traceable and Repeatable
The MAX corrections allow the rover to measure a baseline to the master station – a real reference station. Therefore, the measurements are traceable and repeatable (Fig 6).

SUMMARY OF THE EVALUATION OF FOUR NETWORK RTK METHODS

	Dependent Errors Minimize Distance	Traceability and Repeatability	Consistency	Maximize Use of all Satellite Data	Standardized Method	Rover-controlled Network Solution
Vrt. Ref. Stn.	Y	N	N	N	N	N
i-MAX	Y	Y	Y	N	N	N
FKP	Y	Y	Y	?	N	N
MAX	Y	Y	Y	Y	Y	Y

Table 1: Summary evaluation the four different Network RTK methods

Table 1 provides a summary of the evaluation of four Network RTK methods against the previously mentioned criteria.

MAX is the only method that meets all criteria required by the user to achieve the best possible RTK solution. This is why a user should request MAX corrections from their Network RTK Service Provider.

Your Leica GPS1200 system will always provide the best performance possible within the fundamental limitations of Virtual Reference Station, FKP and i-MAX corrections. However, you will get even more performance with MAX.

NEXT NEWSLETTER – A CASE STUDY

The next Newsletter describes and discusses some case studies where different Network RTK methods are being used. It includes the issues of accuracy, repeatability and reliability.

REMEMBER

- MAX is the only internationally standardized Network RTK method.
- MAX is the only method that gives the rover the control to calculate distance dependent error corrections itself, meaning the rover can adapt its calculations as it determines necessary (local environmental changes).
- MAX is the most advanced method using the whole network information.
- MAX uses only observations from real reference stations (traceability and repeatability).
- MAX provides consistent results.
- i-MAX is the best individualized Network RTK method.
- i-MAX was developed for older receivers that cannot support MAX.
- The i-MAX, Virtual Reference Station and FKP methods do not conform to the philosophy of RTCM's industry standard formats because the messages contain modelled data and not raw data as specified by RTCM.
- Your Leica GPS1200 system will always provide the best performance possible within the fundamental limitations of Virtual Reference Station, FKP and i-MAX corrections. However, you will get even more performance with MAX.

Literature:

Euler H.-J., Keenan R., Zebhauser B., Wübbena G. (2001) Study of a Simplified Approach in Utilizing Information from Permanent Reference Station Arrays. Proc. ION GPS 2001, Sept. 2001, Salt Lake City, USA (www.leica-geosystems/downloads/)

Landau H., Vollath U., Chen X. (2003) Virtual Reference Stations versus Broadcast Solutions in Network RTK - Advantages and Limitations. Proc. GNSS 2003, April 2003, Graz, Austria

Wübbena G., Bagge A., Schmitz M. (2001) Network-Based Techniques for RTK Applications. Proc. GPS JIN 2001, GPS Society, Japan Institute of Navigation, Nov. 2001, Tokyo, Japan