AN Introduction

An RTK Network is a network of permanent GPS and/or GNSS receivers whose combined data is used to generate RTK corrections for a rover – these network generated RTK corrections are called Network RTK.

RTK Networks can vary in size, from small local networks consisting of only a few reference stations, to dozens of reference stations covering a whole country.

A user subscribes to a Network RTK Service to receive RTK corrections with their rover (instead of setting up their own reference/base station).

These RTK corrections can be generated by more than one method - Master-Auxiliary corrections (MAX), Individualized MAX (i-MAX) and Virtual Reference Station – more information on these methods in the next section.

But before going too deep it is useful to give an overview of what exactly Network RTK is. The easiest way to explain this is by comparing Single Reference Station RTK and Network RTK.

Single Reference Station RTK

RTK rovers traditionally receive RTK data from a single RTK reference station. The reference station may be permanently setup (e.g. on the roof of the office) or it might be temporarily set up in the field. In both cases the principle is the same.

The Principle

The principle of Single Reference RTK begins with a single reference station that is:

1. Setup up on a known point; and
2. Sending corrections to the rover via a communication link (normally a one-way radio modem or GSM connection) (Fig. 2).

There are three important points to note in the relationship between the reference station and the rover:

1. Both the reference and rover are observing a common set of satellites.
2. The reference sends all its position and satellite observations to the rover.
3. The rover combines these reference station observations with its own observations to compute an RTK position.

The position is computed using RTK algorithms. Recent advances in RTK algorithms allows the rover to successfully and repeatedly work at distances of up to 50km from the RTK reference station.

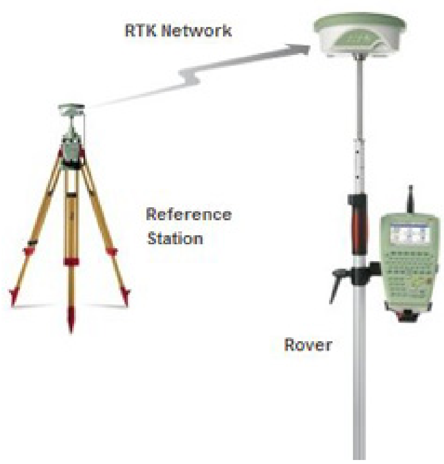

Figure 2: Principle of single baseline RTK

Advantages of Single Station RTK

- The principle is relatively straightforward and generally well understood.
- Traceability can be maintained through the reference station being setup on a known point and the rover managing all the position calculations.

Disadvantages of Single Station RTK

- The cost to purchase the reference station.
- The time needed to setup the reference station.
- As the distance increases between the reference and the rover the accuracy of the rovers computed position decreases.

This decrease in accuracy is due to distance dependent errors – mainly atmospheric errors. Essentially, as the distance between the rover and the reference station increases, the atmospheric conditions at the rover and reference station will become increasingly different. This decreases the accuracy and makes it more difficult for the rover to fix the ambiguities.

Network RTK

Network RTK requires a recommended minimum of five reference stations (there is no maximum) with an inter-station spacing of up to 70 km. The reference stations are usually permanent installations and form the RTK Network , which is the backbone of the Network RTK principle.

The Principle
The principle of Network RTK begins with all reference stations within the RTK Network continuously streaming satellite observations to a central server running Network RTK software.

The aim of Network RTK is to minimise the influence of the distance dependant errors on the rovers computed position within the bounds of the network. The Network RTK server software begins this process by:

1. Fixing the ambiguities of the satellites (being observed by the reference stations) within the network; and
2. Using the data from all (or a subset of) reference stations to generate corrections that are sent out to the rover (Fig. 3).

The rover connects to the Network RTK server via a one-way or two-way communication link (e.g. radio modem, GSM or Internet). Once the rover receives the RTK data it computes its position using the appropriate algorithm.

Which algorithm the rover uses, and how the distance dependent errors are minimized is very much dependent on the Network RTK method being used.

Previously we mentioned MAX, and Virtual Reference Station as examples of Network RTK methods available in the market - each of these methods minimizes (or models) the errors in different ways. Depending on the method, this modeling is either carried out on the Network RTK server or at the rover. Therefore, the relationship between the RTK Network and the rover is different for each method which can lead to significant differences in performance, accuracy, reliability and traceability for the rover.

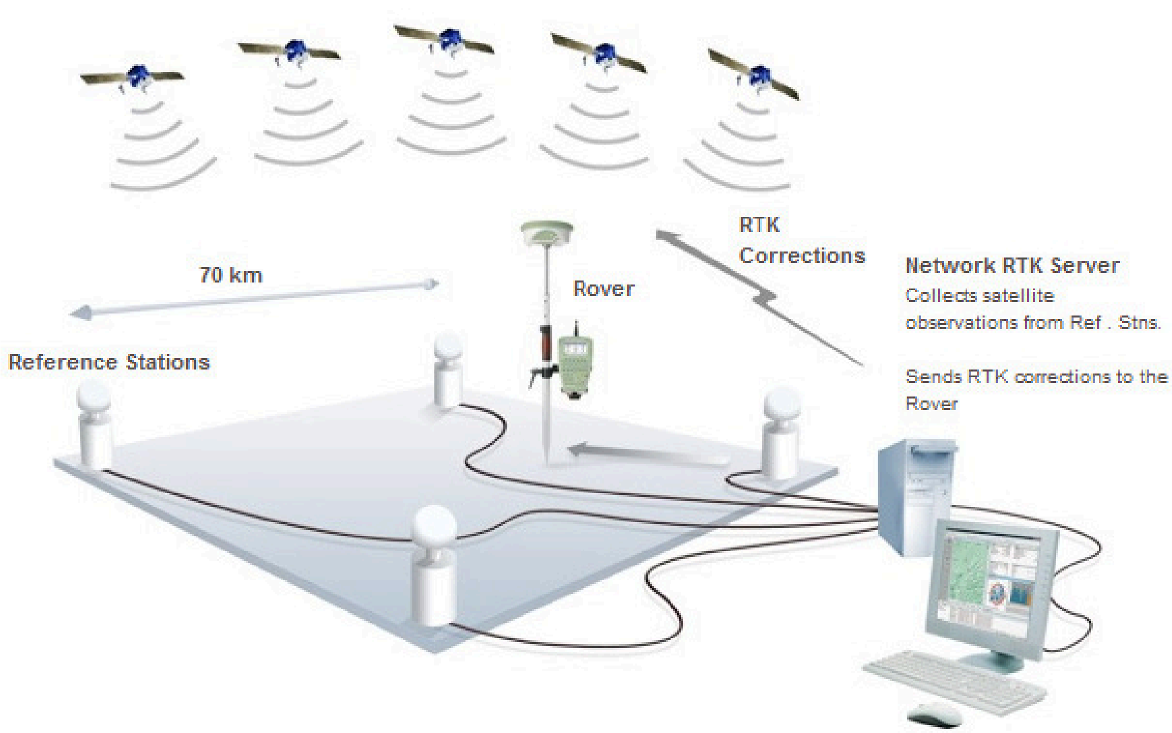

Figure 3: Principle of Network RTK

Advantages of Network RTK

- No need to set up a base station
- The accuracies of the computed rover positions are more homogeneous.
- The accuracy is maintained over larger distances between the reference stations and the rover.
- The same area can be covered with fewer reference stations (i.e. compared to the number of permanent reference stations required using Single Reference RTK).
- Higher reliability and availability of RTK corrections (e.g. one station goes down, another station can take over).

Disadvantages of Network RTK

- The cost to subscribe to an RTK Network and receive Network RTK corrections Now we have an overview of how Network RTK works the main question is: Is it economically worth subscribing to an RTK Network and receiving Network RTK corrections? The time needed to setup the reference station.

Network RTK — Is it worth it?

Lets consider a surveyor in the US as a typical example.

SmartNet North America offers a state level annual subscription for around $ 2,400. This means that anywhere, anytime within that service area, the Surveyor can receive RTK corrections for their rover with no need to ever setup their own base station.

$ 2,400 is not a small sum of money. But assume the Surveyor completes an average of 2-3 jobs per week for 50 weeks of the year using Network RTK this is a total of around 100 jobs per year.

The cost per job to receive Network RTK correction is therefore $ 24 per job. So the question for the Surveyor to answer is, can I save $ 24 per job by not using a base station? Consider the following.

Firstly, the surveyor saves time by not needing to do the following:

- Researching a known point to setup the base station over.
- Arranging a power-supply (e.g. batteries) for the base station.
- Travelling to the base station location (which may not always be conveniently located next to the site where he is working).
- Setting up the base-station.
- Securing the base station (i.e. do not need to worry about it being stolen or knocked over).
- Packing up the base station at the end of the job.

Secondly, the surveyor saves money by not needing to purchase:

- A base station.
- Base station accessories (radios, batteries, tripod, etc.).
- Labor for the time spent doing the tasks listed earlier (which may also include to pay someone to simply sit by the base station to ensure it is not stolen)
- Maintenance for the base station and accessories.

In the next section lets look, other advantages include:

- The removal of some potential error sources (e.g. not needing to plumb a base station and measure its height).
- Less equipment to move/transport. The list probably goes on. So lets look at an example of how using an RTK Network might benefit a surveyor.

Example — Using Network RTK

In this example there are two surveyors, Surveyor A and Surveyor B. Both surveyors have the same two jobs to complete, Job 1 and Job 2. Each job takes 30 minutes to walk around all the required points. The jobs are spaced 35 km apart.

Surveyor A

Surveyor A is using a Network RTK capable GNSS Rover to receive RTK corrections from SmartNet. Surveyor A takes the following steps to complete Job 1 (Fig. 4):

1. Drive to Job.
2. Setup the rover.
3. Connect to SmartNet to receive RTK corrections.
4. Walk around and measure points.
5. Disconnect from SmartNet.
6. Pack up rover.

Surveyor A then repeats steps 1 6 for Job 2 (Fig. 5) with the final step of driving back to the office.

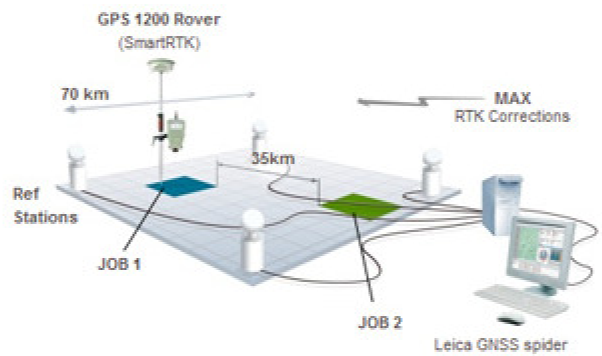

Figure 4: Surveyor A completing Job 1

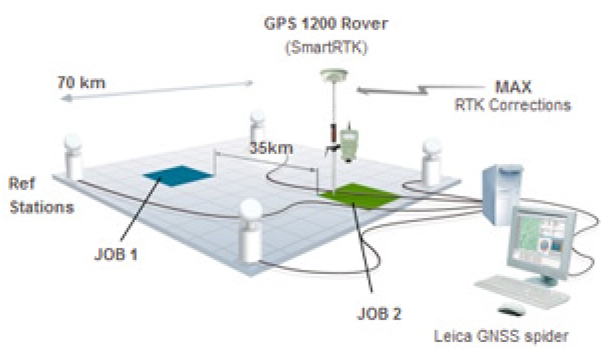

Figure 5: Surveyor A completing Job 2

Surveyor B

Surveyor B is using a base station and rover either with either a traditional RTK radio setup or a pair with cellular data devices providing the communication link. Surveyor B takes the following steps to complete Job 1 (Fig. 6):

1. Drive to Job.

2. Setup base station in a suitable location, which may or may not be adjacent to the working area.
3. Measure height of base station.
4. Start the base station broadcasting RTK corrections.
5. Go to the start of the job.
6. Setup the rover.
7. Connect rover to the base station to receiver RTK corrections.
8. Walk around and measure points.
9. Pack up rover.
10. Return to the base station.
11. Re-measure height of base station (to check that it has not moved).
12. Pack up base station.

Surveyor B then repeats steps 1 12 for Job 2 (Fig. 7) with the final step of driving back to the office.

Surveyor B could also choose to leave the base station setup at Job 1 and carry on to Job 2 (Fig. 8).

In this case, by increasing the distance between the rover and the reference to 35 km, there would be an associated decrease in accuracy of the rovers computed position. Therefore, Surveyor B would be sacrificing accuracy in favor of saving time on the setting up of the base station. Surveyor B would also have the additional step of collecting the base station before returning to work.

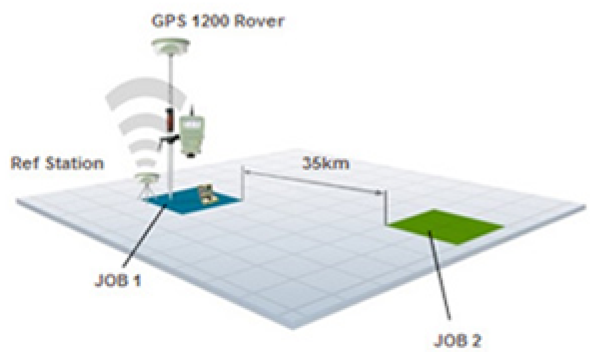

Figure 6: Surveyor B completing Job 1

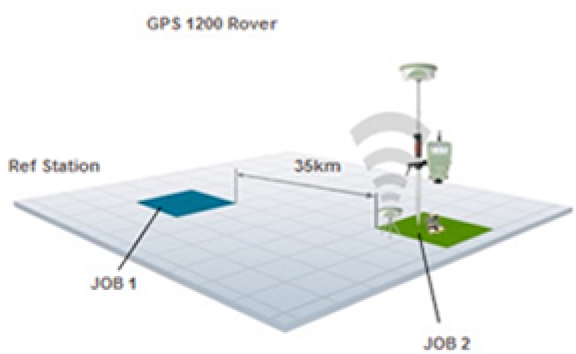

Figure 7: Surveyor B completing Job 2

Summary

By not needing to setup a base station, Surveyor A had a lot less work to do in the field than Surveyor B. In addition, Surveyor A avoided potential risks such as:

- The base station battery going dead.

- The base station radio battery going dead.
- The base station being moved (e.g. cattle, wind, traffic or thieves!).

Surveyor B could have setup and packed up their base station twice, or simply left the base station at the first setup sacrificing accuracy for convenience. So what is the real world cost of performing the survey using Surveyor B's procedures over the course of a year? Well if we assume that it takes an hour to setup and tear down the base station and Surveyor B uses GPS 3 days a week, then it is simply $ 100 / hour x 3 days a week x 50 weeks a year, or $ 15,000 in lost production time!

In contrast, by using SmartNet, Surveyor A could achieve consistent accuracy for both jobs, as well as dramatically increased his productivity. No sacrifices were made.

Different Methods

The previous section focused on the economic advantages of using a RTK Network as an alternative to setting up your own reference station.

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

In the previous section 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).

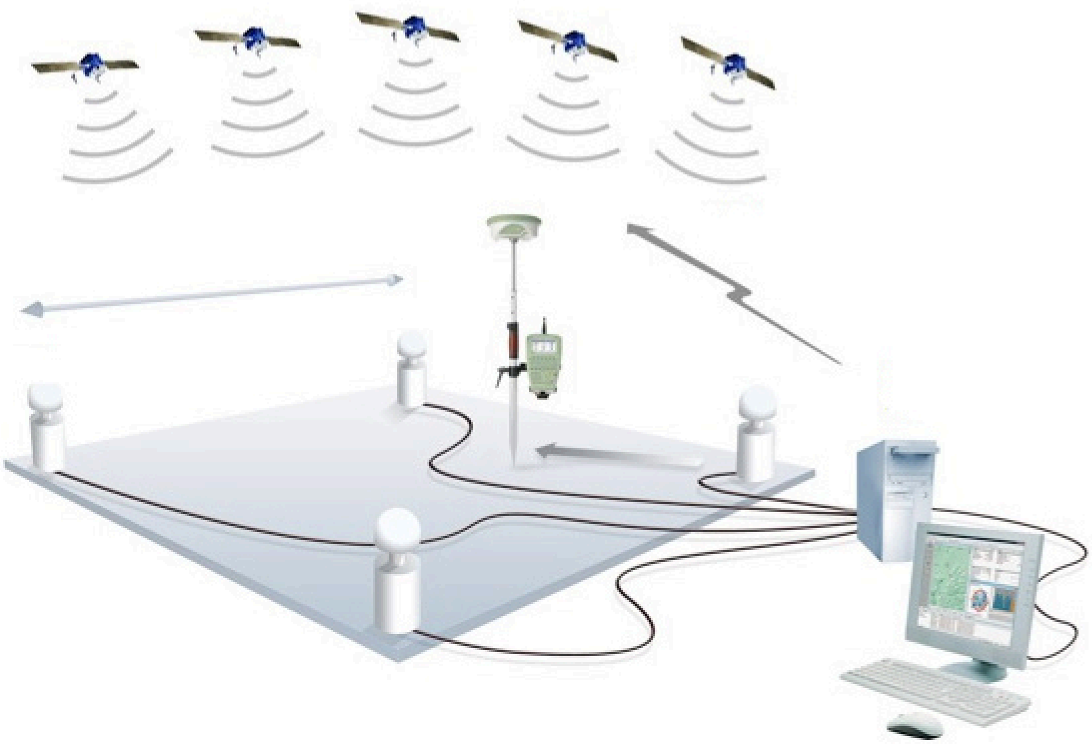

Figure 1: The Role of the Network RTK Server

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 Section 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 Section 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.

Evaluating Network RTK Methods

We described in the previous Section 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.

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 maximize the rover's ability to calculate a RTK solution, the Network RTK method needs to maximize 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.

Network & Rover Relationship

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

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

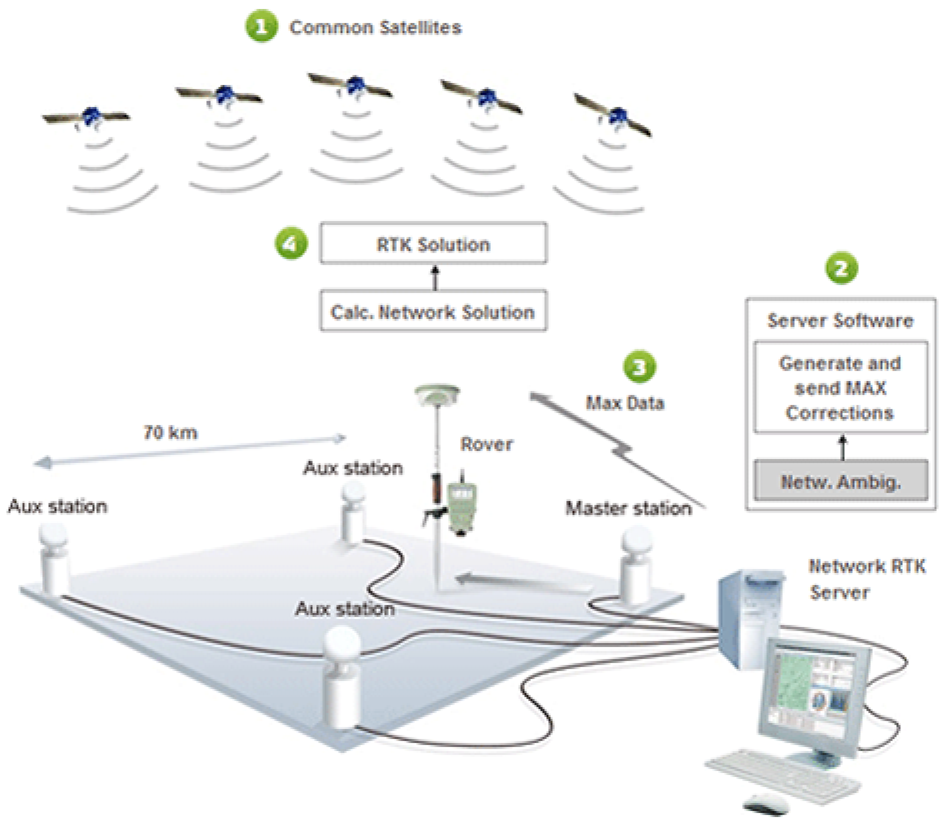

Figure 2:
Four basic parts of the relationship between the server and the rover in Network RTK

Four Basic Parts

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 nonstandard (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 Three Different Methods

Master-Auxiliary Corrections (MAC or MAX)

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 Virtual Reference Station Method (ViRS)

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

i-MAX & Virtual Reference Station

The Method

The methods of i-MAX and Virtual Reference Station (ViRS) 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 ViRS 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 maximized

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

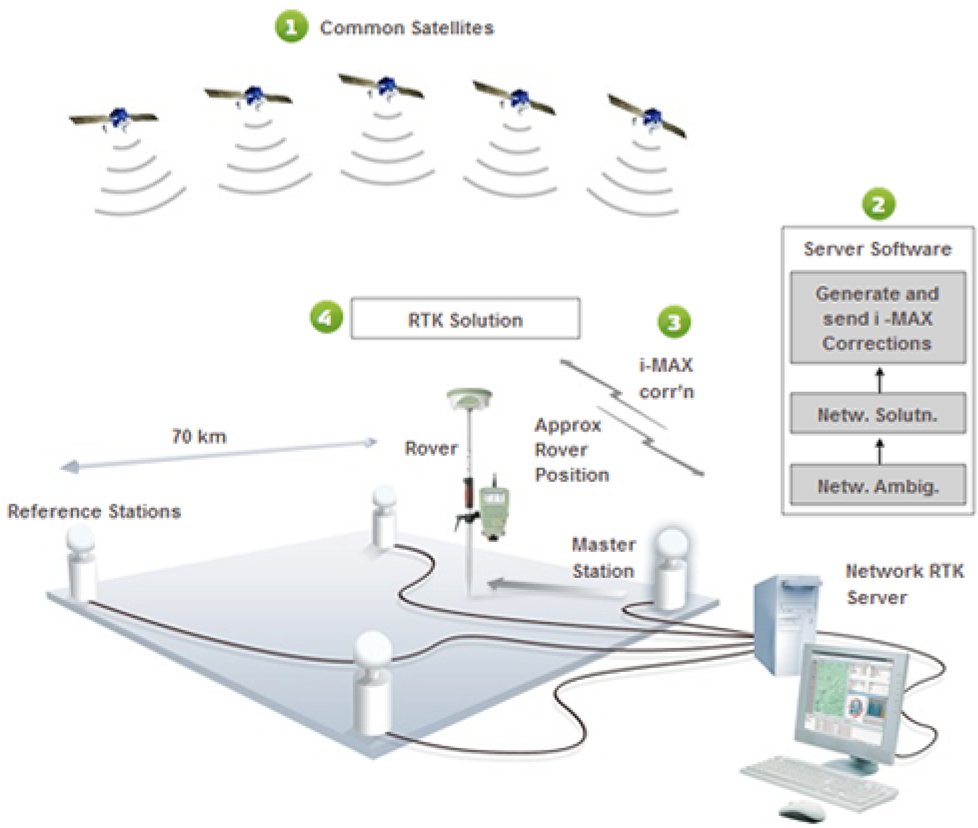

Figure 3: The relationship between the server and rover using i-MAX

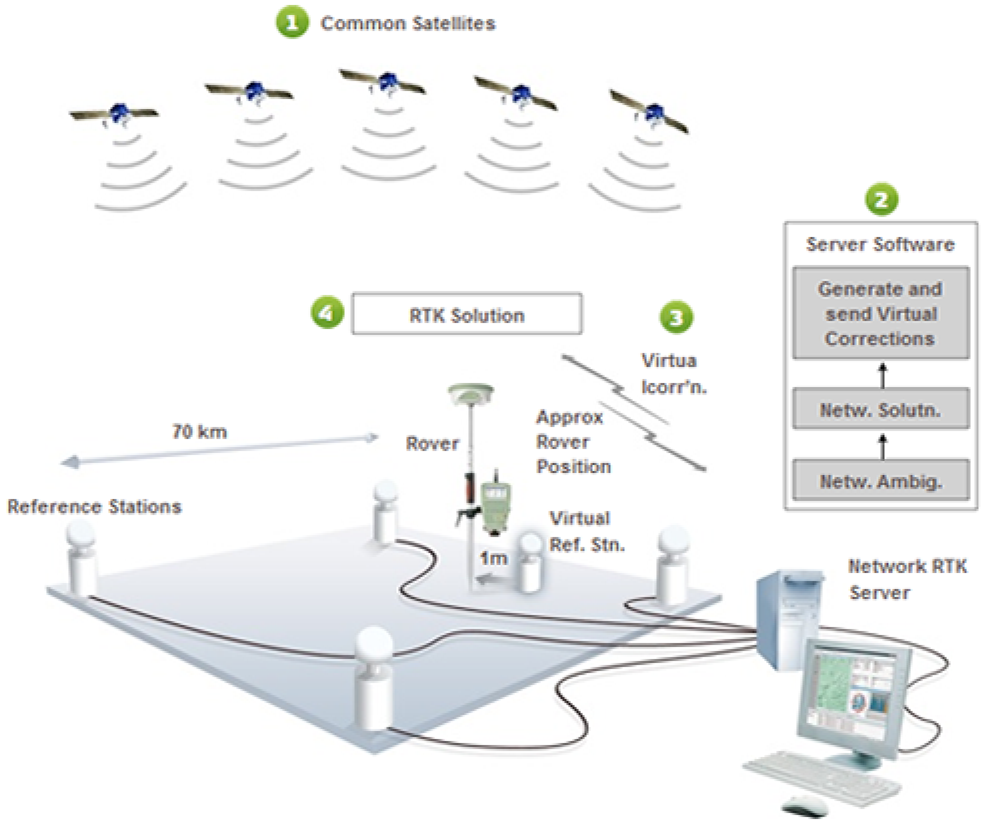

Figure 4: The relationship between the server and rover using ViRS

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 bas eline 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 directly re-measured. This violates the fundamental surveying principles of traceability and repeatability (Fig 4).

Consistency

The Virtual Reference Station corrections are optimized 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.

Master—Auxiliary 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 5.

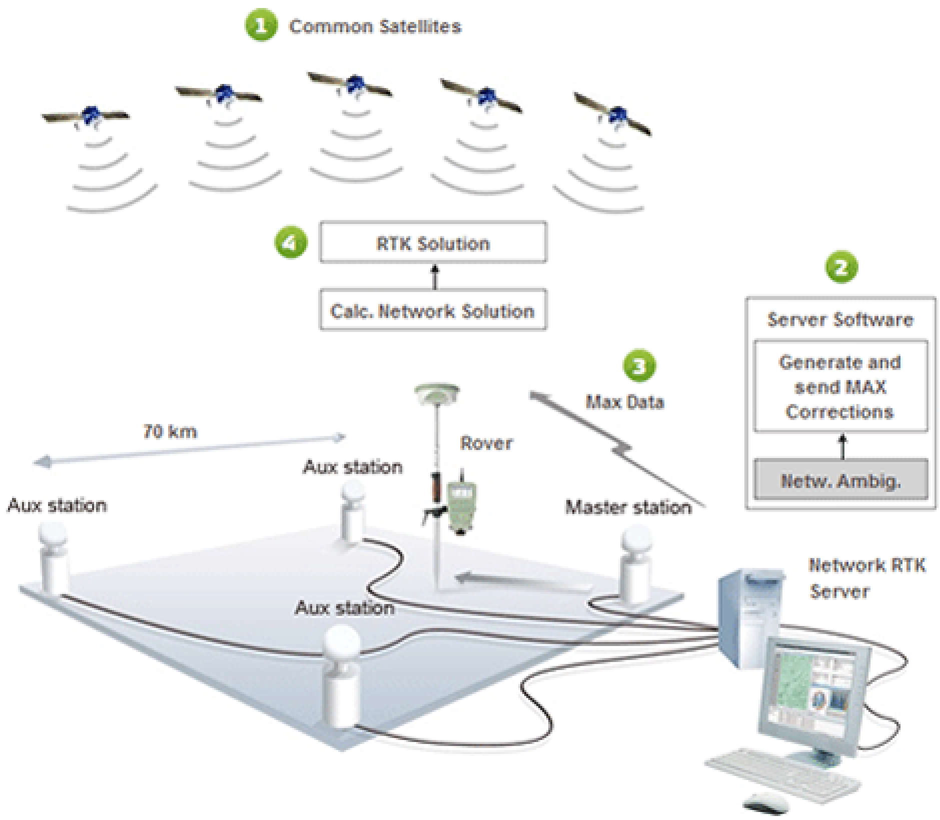

Figure 5:
The relationship between the server and the rover using the Master-Auxiliary Concept method

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 Three Methods

	ViRS	i-MAX	MAX
Rover Controlled Solution	✗	✗	✓
Standardized Method	✗	✗	✓
Maximize Use of all Satellite Data	✗	✗	✓
Consistency	✗	✓	✓
Traceability & Repeatability	✗	✓	✓
Minimize Distance Dependent Errors	✓	✓	✓

Table 1: Summary evaluation the three different Network RTK methods

Table 1 provides a summary of the evaluation of three 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 and i-MAX corrections. However, you will get even more performance with MAX.

Remember!

- Master-Auxiliary Concept (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 and Virtual Reference Station methods do not conform to the philosophy of RTCM's industry standard formats because the messages contain modeled 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 and i-MAX corrections. However, you will get even more performance with MAX.

SmartNet North America
Any Constellation - Any Application - Open to All