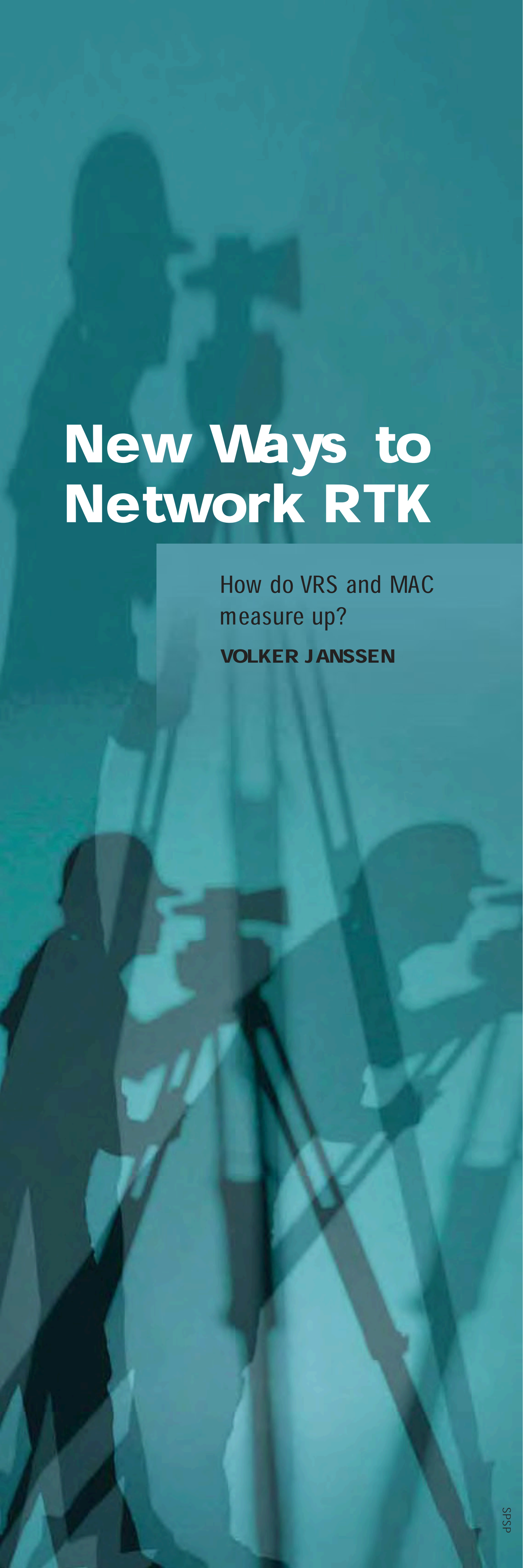

SPSP

New Ways to Network RTK

How do VRS and MAC measure up?

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The concept of Network Real Time Kinematic observations was introduced in the mid-1990s. It has been progressively developed into the commercially viable systems available now.

Conventional single-base RTK is limited to distances of 10-20 kilometres from the base station. Long-range RTK made it possible to observe baselines of up to about 50 kilometres. However, by using the information from a network of continuously operating reference stations, highly accurate positioning is now achievable over distances of several tens of kilometres.

This article compares the two most prevalent methods, the Virtual Reference Station (VRS) approach and the Master-Auxiliary Concept (MAC). Most manufacturers support both methods.

NRTK works by modelling error sources – primarily the ionospheric and tropospheric delays and orbit errors – and representing them as real-time corrections for roving receivers.

The ionospheric delay is dispersive; it affects different frequencies in different ways. This characteristic is used to estimate the error by combining observations on two frequencies. In contrast, the tropospheric delay and orbit errors are non-dispersive, so equally affecting signals on different frequencies.

VRS is a technique in which data is created for an ideally placed virtual station from a network of reference stations. They are permanently linked to a control centre, which creates a database of regional area corrections across the network. These corrections are then used to create the virtual reference station, situated only a few metres from the rover. The rover uses the data as if it had come from a real reference station.

The implementation of the VRS technique requires at least three reference stations connected to a network server. The rover must be capable of two-way communication. The user starts by connecting to the VRS network service via a mobile phone capable of data transfer. The rover sends its current position to the computing centre in National Marine Electronics Association (NMEA) format.

The control centre takes this position as the location of a new reference station, calculates corrections, and transmits these to the rover. This effectively reduces the RTK baseline length to be processed and incorporates the error information obtained from the surrounding network stations. On the rover side, standard single-base RTK algorithms are employed to obtain a position fix.

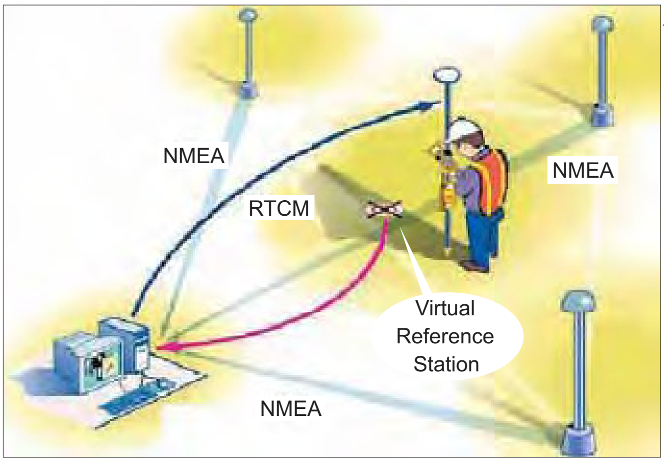

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Figure 1: The principle of VRS. The receiver sends its approximate position to the base station. A set of reference stations sends NMEA-format signals as well. The base station interpolates the errors at a virtual reference station and then sends the correction signals to the rover.

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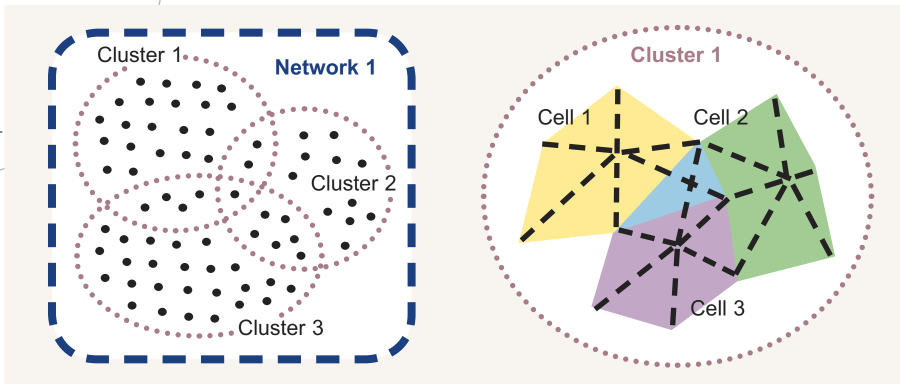

Figure 2: Several clusters in a MAC network, and to the right, a cluster providing master-auxillary corrections to several rovers, with each rover using an appropriate cell based on its location.

Thus, the VRS network provider has to perform the following steps:

1. Determine atmospheric and orbit errors by fixing the ambiguities of the baselines in the network
2. Simulate the position of the VRS by displacing the data of the reference station closest to the rover
3. Interpolate network errors at the VRS location using linear or more sophisticated models
4. Transmit the corrections

MAC works differently. Corrections are transmitted to the rover in a highly compact form. Ambiguity-levelled observations are represented as differences of dispersive and non-dispersive data for each satellite receiver pair.

Two reference stations are said to have common ambiguity if the integer ambiguities for each phase range –or satellite-receiver pair – have been adjusted so they cancel. This is done by creating double-differences. It involves two receivers and two satellites.

The rover uses the data as if it had come from a real reference station...

In order to reduce the volume of data transmitted, full correction and co-ordinate information is sent only for a single reference station (the master station).

For all other stations in the network (the auxiliary stations), correction and co-ordinate differences are transmitted. Splitting the corrections into dispersive and non-dispersive further reduces the bandwidth required. Non-dispersive differences change slowly over time, so the data rate does not need to be as high as for the dispersive error.

Since the master station is used simply for data transmission, and plays no special role in the computation of corrections, it does not need to be the closest reference station to the rover.

The user can receive these NRTK messages either in broadcast mode – as one-way communications – or in automatic mode, as two-way communications. In broadcast mode, the master station is predetermined. In automatic mode, it will be the closest station to the rover.

For practical reasons, network processing and the distribution of corrections are based on a tiered system of networks, clusters and cells. A cluster is a subset of the network stations that are processed together to achieve a common ambiguity level. Individual sites may be in more than one cluster, allowing overlap between them. A cell is a selection of at least three sites from a single cluster. It has one master station. The cell is used to generate the so-called master-auxiliary corrections (MAX) for the user.

The MAX contains the MAC network corrections. The rover performs the interpolation of the network corrections using the full information of the network. However, it is only available for rovers that support RTCM 3.1 network messages.

There is a difference between broadcast-MAX and auto-MAX. Broadcast-MAX is applicable with radio and other one-way communication media, and uses fixed cells that are defined by the network operator. This means that users must connect to a suitable correction service (i.e. cell). 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.

Auto-MAX requires two-way communication, allowing an appropriate cell to be chosen automatically. This is based on a NMEA string containing its approximate position received from the rover.

It is also possible to automatically choose a cell predefined by the network operator, and this may be configured to update, based on the movement of the rover. The nearest station to the rover is always chosen as the master station. Auxiliary stations are selected from the surrounding stations to provide the best possible set of corrections for the rover's position.

To support receivers that cannot interpret the RTCM 3.1 NRTK messages, individualised master-auxiliary corrections (i-MAX) are produced. These i-MAX corrections require two-way communication. The operator chooses the appropriate cell and interpolates the network corrections for the rover's position.

Highly accurate positioning is now achievable over several tens of kilometres...

The corrections are based on the same interpolation algorithm used with other MAX corrections, and can be transmitted in the RTCM 2.3 and RTCM 3.1 single-base formats. The basic steps in the use of i-MAX are analogous to MAX, with the exception that the network server calculates the NRTK corrections for the rover and applies them to the master station.

i-MAX is very similar to VRS. It has many of the same problems. In both cases the network server calculates corrections using proprietary algorithms. Two important differences are:

1. i-MAX always uses a physical reference station and not a virtual one, enabling consistency and traceability for the corrections received by the rover.
2. Base stations may be 70 kilometres apart; baselines may be 40 kilometres or more. This might be a problem for older rovers, as they are sometimes hardwired to prevent use of long baselines.

In short, the advantage of VRS is that it allows complex modelling of atmospheric effects in the server using the full network information. No complex computations are needed at the rover. It is also well suited for commercial applications. For instance, billing is incorporated into the system and readily managed due to two-way communication, and it provides support for older rovers because the data stream from VRS mimics conventional RTK.

One disadvantage is that it requires two-way communication. A new VRS has to be determined if the rover moves too far from the original VRS. Additional area correction parameter information (in German, *Flächenkorrekturparameter* or FKP) is provided, enabling the rover to correct local effects through a linear FKP model.

Additionally, modelling is performed by the network software. It influences the information sent to the rover, potentially prohibiting it from using the optimal processing techniques for the application.

Another problem is that it infringes the RTCM philosophy. The VRS and FKP messages contain modelled data, where traditional RTCM contains raw data. This means that the VRS user receives no information about the size of the errors or corrections.

VRS also suffers because it simulates the network as a single reference station. This causes the rover to mimic a single-base RTK solution over a short distance. Generally, the rover does not derive an ionosphere-free solution that can eliminate residual errors not modelled by the network.

Finally, there are possible legal issues with regard to traceability, because the GNSS correction data is not directly linked to a real physical reference station.

On the other hand, MAC's advantages are that it supports both one-way and two-way communication and supports old receivers through i-MAX.

Complete information on the prevailing error sources is made available to the rover through RTCM network messages. This facilitates the use of more intelligent positioning algorithms in the determination of the rover's position.

Most rovers in the future will be capable of two-way communication...

MAC conforms to RTCM philosophy by transmitting unmodelled (albeit ambiguity-levelled) reference station data to the rover. The exception is i-MAX, which uses proprietary software to determine the corrections.

It also has advantages when the rover moves large distances. In auto-MAX mode, a different cell is formed instantly when the rover moves. This is possible since the entire cluster is on the same ambiguity level.

Finally, it offers clear legal traceability. The GNSS correction data is directly linked to a real reference station.

It is also noteworthy that VRS, as well as FKP, MAX and i-MAX can all be deduced from MAC data.

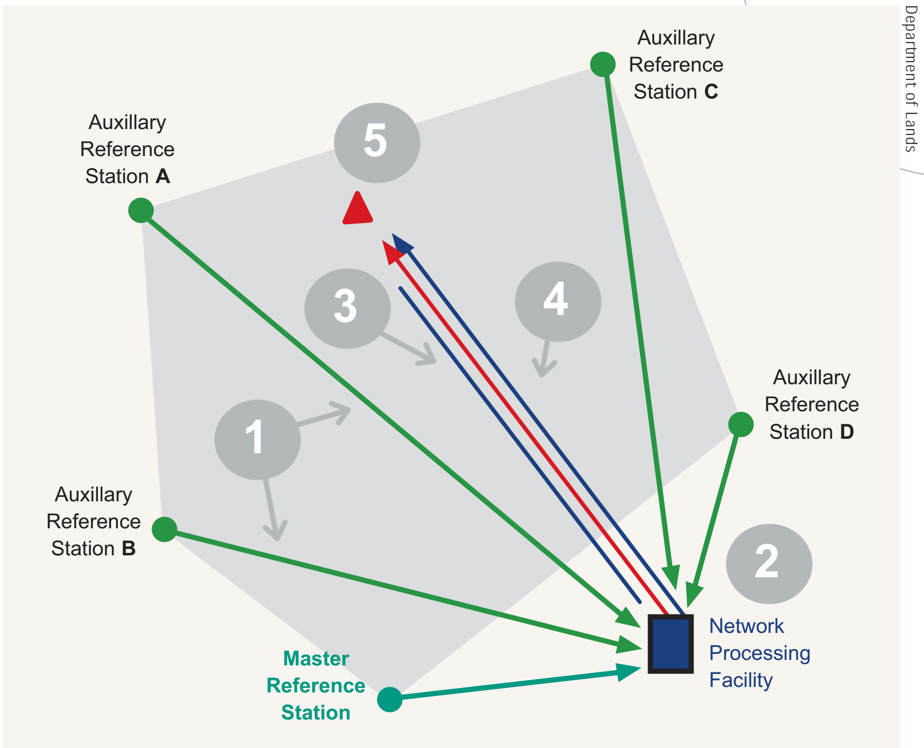

Figure 3: The principals of MAX: Point 1 indicates the transmission of raw observables from the reference stations to the network processing facility. Point 2 is the network estimation process, including ambiquity resolution. Point 3 is the position received from the rover. Point 4 is the transmission of a network message using corrections for the master station and correction differences for the auxillary stations. Point 5 is the computation of a high-accuracy rover position using the full information for the reference networks.

Among its disadvantages is that billing is more complex for commercial users in broadcast mode. The rover is required to perform the bulk of the processing, which may influence the expected trend in the future towards dumb rovers for mass-market, non-survey applications.

In broadcast mode, the user needs to consciously select a certain cell that is predefined by the network operator and may not be ideal.

In a direct comparison to VRS and FKP, MAC demonstrated better performance in terms of time-to-fix, reliability of ambiguity resolution and accuracy for the rover. This was despite a lower update rate of five seconds being used for the network corrections.

From the user's perspective, both methods are supported by the leading GNSS equipment manufacturers and deliver positioning results at the same accuracy level.

In the VRS approach, the network server carries out the bulk of computations, while MAC requires the rover to be responsible for most of the calculations. This obviously has implications for the rover equipment required.

However, while VRS rovers need to trust the proprietary processing steps performed by the network server, either a simple or a more complex interpolation algorithm can be applied in a MAC rover, depending on its capabilities. In future, most rovers will be capable of two-way communications.

The level of sophistication in the processing is up to the rover, which accounts for the needs of both commercial users and the research community. The VRS approach was developed in order to make use of the limited capabilities of rovers at the time. The MAC approach takes full advantage of recent developments in technology, in particular the ability to transmit NRTK corrections in RTCM format.

From the network provider's perspective, the MAC approach appears to be superior. It supplies users with raw correction data – conforming to the RTCM philosophy – rather than modelled data, relating to real rather than virtual reference stations.

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