WHITE PAPER

DYNAMIC STATION COORDINATES APPROACH TO IMPROVE NETWORK/FIELD PERFORMANCE

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INTRODUCTION

Accurate reference position information is essential in Network-RTK positioning to be able to generate reliable correction data. The principle of Network-RTK is that a significant portion of ionospheric, tropospheric and ephemeris errors are estimated over a region and this information is provided to Rovers in the field. The influence of the ionosphere is mostly reflected in a biased 2D position, whereupon the troposphere mainly influences the height component of a position. Incorrect reference position information therefore results in biased ionospheric and tropospheric estimations, which finally have a negative input on the Rover position performance in the field. Rapid movements such as earthquakes or constant position offsets found in local networks are error sources for incorrect position information.

This paper presents a solution offered in Trimble Pivot Platform (TPP) to avoid the influence of biased position information during Network-RTK positioning.

TRIMBLE PIVOT PLATFORM SOLUTIONS

The Trimble Pivot Platform (TPP) for software applications is the framework on which the solutions discussed here operate on. The TPP provides a system architecture that ensures reliable operation and allows customers to pick and choose the exact functionality required in the form of apps that operate on a common foundation.

Figure 1 shows the Pivot platform application hierarchy, which is described in greater detail in the Trimble Pivot Platform Technical Note[1].

Footnote: 1: http://trl.trimble.com/docushare/dsweb/Get/Document-645735/022506-149A_TrimblePivot_TN_1112_LR.pdf

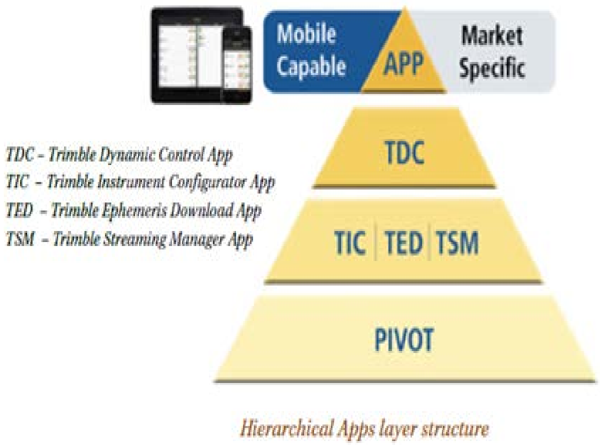

Figure 1: Pivot Platform hierarchical apps layer structure

WORKFLOW FOR EACH APPROACH

For each base station, the user enters a coordinate (RS coordinates) in TPP. This coordinate represents the position of the station in a selected reference frame and time, e.g. ITRF2008, ETRS89. The reference frame and time can be selected by the user in the TPP system properties for each station or as a general setting and output individually.

To estimate the ionosphere and troposphere delay using the Network processor or RTXNet Processor, the RS coordinates are transformed into a global coordinate system with ITRF 2008 frame and current epoch reference time (ITRF2008 Current Epoch).

These global coordinates are used to initialize the processor. This approach is referred in this document as the "traditional approach".

In this approach, the RS coordinates can be biased:

1. **Internal factors**: receiver coordinates are incorrect; antenna height is inaccurate; receiver firmware and antenna information not updated, etc.
2. **External factors**: the GNSS antenna experiences shifts due to earthquakes, volcano eruptions, postglacial land rise, etc.

RS coordinates' position errors are propagated (see figure 2).

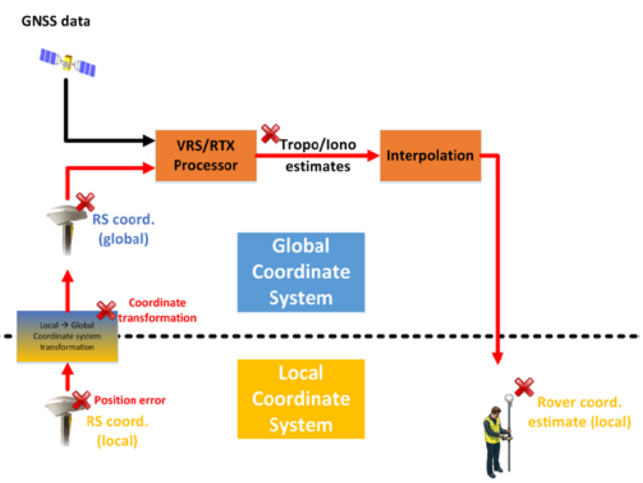

Figure 2: Rover coordinate estimation using Reference Stations with the traditional approach

Initially, when RS coordinates are transformed from the local to the global coordinate system and are used to initialize the processor, the processor calculates the atmospheric corrections containing the bias from the RS coordinates. Errors within atmospheric corrections are further propagated since these corrections are used to estimate the correction data at the Rover position.

With the Dynamic Station Coordinates (DSC) approach, local coordinates are not used to initialize the Network processor. Reference Station Coordinates in ITRF2008 Current Epoch are directly estimated by using GNSS data with Trimble RTX™ technology (see figure3):

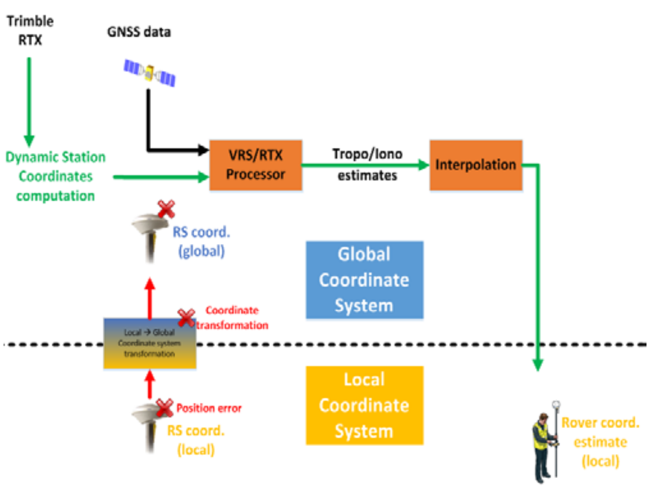

Figure 3: Rover coordinate estimation using Reference Stations with the DSC approach

DSC are continuously computed and updated when necessary.

For each epoch, the internally computed RTX position is fed into two Kalman filters, one configured to expect no movement (static) and the other for sudden movement. The static filter outputs the highest accuracy position, but has a substantial reaction delay to position changes. The sudden movement filter has a fair accuracy and reaction time to movement. By comparing the position from the static and sudden movement filters, unexpected movements of the station can be determined.

Converged position information from the static filter only will be forwarded into the processors. In case of movement detection, no data from the affected station will be processed until the accuracy of the position is below the default thresholds (3σ 2D<1 cm, 3σ Height<2 cm) again.

Thus, the processors are robust against position errors in the RS Coordinates. This approach is referred in this document as the "DSC approach".

TESTING AND RESULTS

A network of seven reference stations and one Rover, located in Bavaria, Germany was used to assess the Rover positioning performance when using the "DSC approach" in comparison to the "traditional approach".

An error of 10 cm in x direction is introduced in 2 stations (C264 and A270) in the network. It is expected that the incorrect position will influence the quality of the network residuals in the case of the "traditional approach".

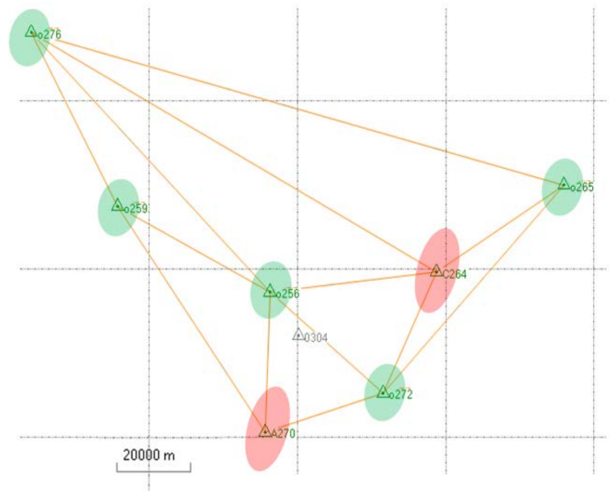

Figure 4: Network with Rover

Data from the Bavarian network described above was processed by Network processors and RTXNet processors. The below four different configurations scenarios were analyzed:

1. Network Processor, with DSC disabled
2. Network Processor, with DSC enabled
3. RTXNet Processor , with DSC disabled
4. RTXNet Processor, with DSC enabled

These network residuals key values were also compared for these scenarios:

IRIM – The Ionospheric Residual Integrity Monitoring (IRIM) index is generated by the network processor which indicates by how much the ionospheric delay differs from a linear spatial variation. It is calculated by omitting one reference station from the interpolation and comparing the interpolation results with the estimated ones. Subsequently, a weighted RMS over all satellites is computed at one epoch and accumulated over one hour to get the 95% distribution. More information about IRIM can be found in the technical notes[2].

GRIM – The Geometric Residual Monitoring index analogously represents the 95th percentile of geometric residuals.

IRIM and GRIM provide the network operator with a better idea of the residual error within the network as well as a good estimate of the interpolation error for users in the field.

The following figures plot the IRIM / GRIM values for Network Processors and RTXNet Processors over a period of 2 days.

Footnote 2: http://trl.trimble.com/docushare/dsweb/Get/Document-183156/ION%202003New%20Tools%20for%20Networked%20RTK%20Integrity.pdf

Network Processor:

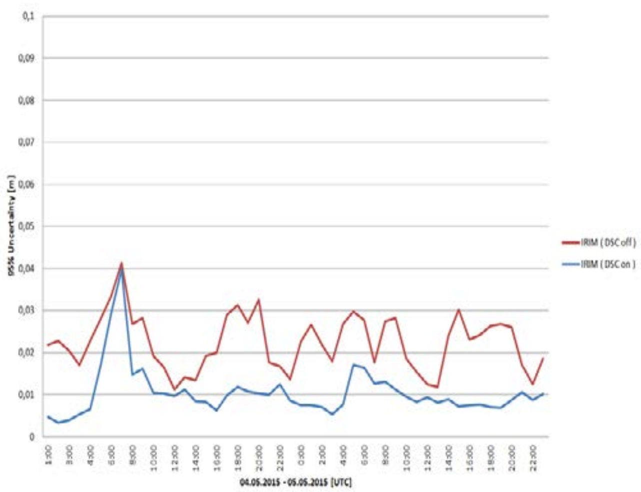

Figure 5: Predicted ionospheric error for Network Processor, with DSC disabled and enabled

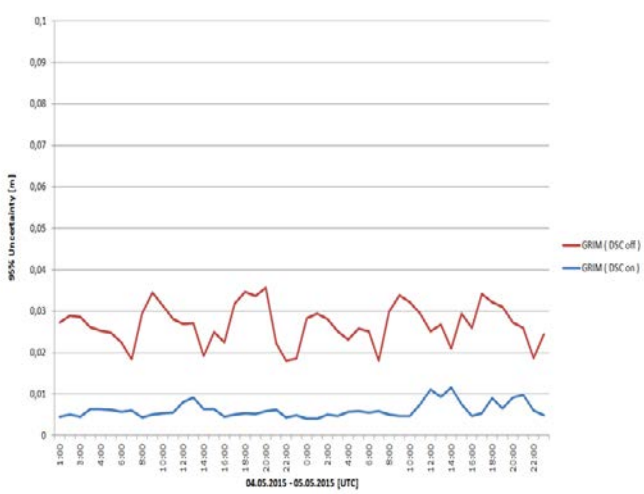

Figure 6: Predicted geometric error for Network Processor, with DSC disabled and enabled

The average predicted ionospheric error has been reduced by approximately 50% (see figure 5), the tropospheric by approximately 76% (see figure 6) for Network Processor.

RTXNet Processor:

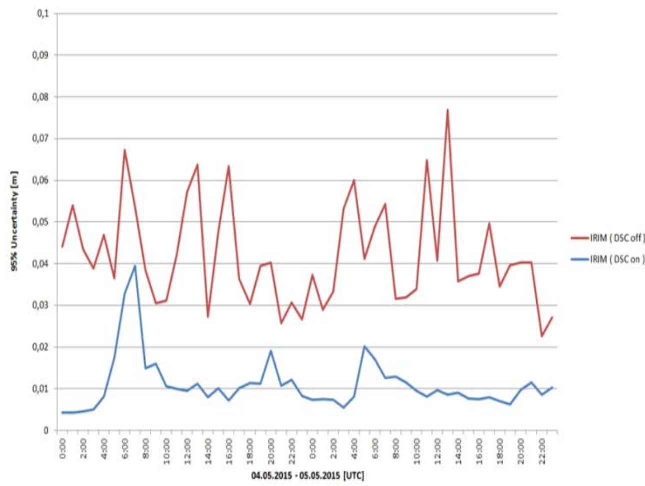

Figure 7: Predicted ionospheric error for RTX Net Processor, with DSC disabled and enabled

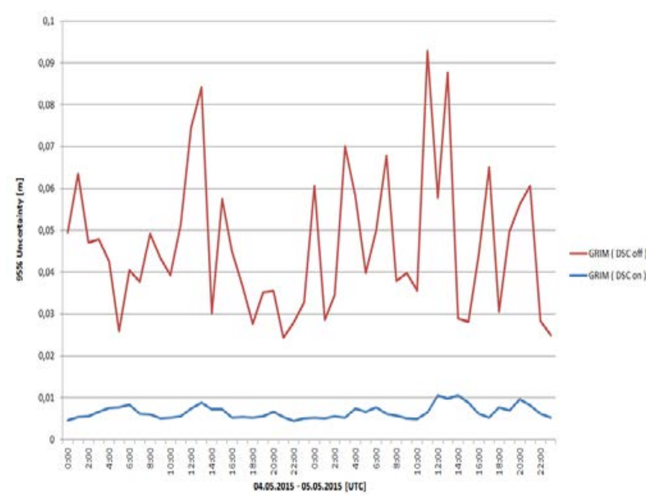

Figure 8: Predicted geometric error for RTX Net Processor, with DSC disabled and enabled

The average predicted ionospheric error has been reduced by approximately 72% (see figure 7), the tropospheric by approximately 84% (see figure 8) for RTXNet processor.

Four Rovers were connected to each of the above processors. All Rovers were located at station 0304. Closest physical base station during the entire test was station o256. The distance between the two stations is approximately 16 km. The following table shows the results from 48 hours of processing.

Processor & DSC	Std. Dev. 2D [m]	Std. Dev. h [m]	95% 2D [m]	95% h [m]	Mean Offset 2D[m]	Mean Offset h [m]
Network & DSC ON	0.006	0.014	0.023	0.031	0.012	-0.005
Network & DSC Off	0.010	0.025	0.047	0.058	0.029	0.012
RTXNet & DSC ON	0.006	0.014	0.023	0.033	0.012	-0.005
RTXNet & DSC Off	0.012	0.053	0.065	0.144	0.022	0.025

Table 1: Rover position statistics

The 2D and height standard deviation with the "DSC approach" is lower than the "traditional approach", both for the Network Processor and RTXNet Processor. Also, 95% of 2D and height position errors decrease when DSC is enabled. With DSC enabled, Network Processor and RTXNet Processor show similar results. Figures 9 and 10 show 3D position offset for each Rover.

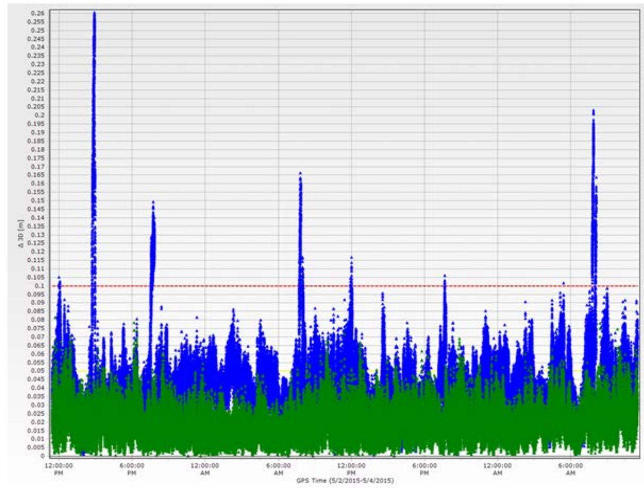

Figure 9: Rover position scatter plot when using corrections from a network of reference stations using network processors with DSC disabled (blue) and DSC enabled (green)

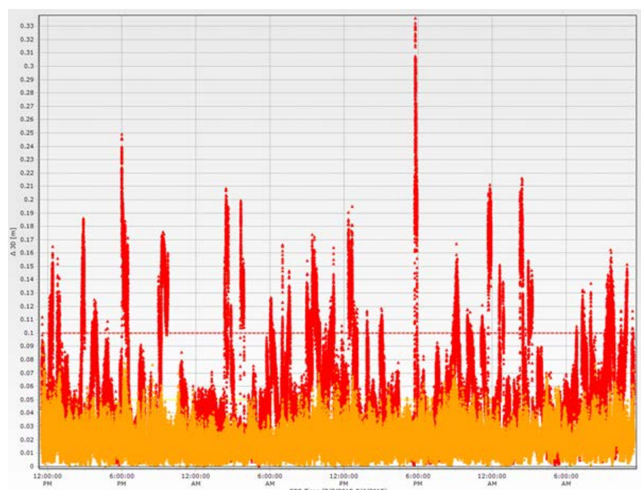

Figure 10: Rover position scatter plot when using corrections from a network of reference stations using RTXNet processors with DSC disabled (red) and enabled (orange)

SUMMARY

This document presented two different approaches when using coordinates of reference stations in a VRS/RTXNet Network.

1. The "traditional approach" uses the local static coordinates of the reference stations. These coordinates contain position errors which are propagated to the Network-RTK corrections (e.g. VRS) and further to the Rover position estimates.

2. The "DSC approach" uses "Trimble RTX" technology to compute the so-called "Dynamic Station Coordinates" for each reference station. These coordinates are dynamically re-computed and updated to best fit the reference stations' position. As a result, the propagation of position error present in the reference stations is minimized and the Rover position estimates improve.

A network with seven GNSS receivers was configured and one Rover in order to compare the performances of both approaches. A 10 cm error was artificially introduced in the reference coordinates of two of these stations.

Each processor type (Network or RTXNet) was combined with the DSC feature (enabled or disabled) with the following results with respect to network and Rover performance.

1. Predicted Ionospheric and geometric errors
   a. Network Processor:
      The Predicted Ionospheric and geometric errors when using Network Processors with the DSC approach (in a 48-hour period) showed an improvement of approximately 50% and approximately 76% (see figures 5 and 6)
   b. RTX Net Processor:
      The Predicted Ionospheric and geometric errors when using RTXNet Processors with the DSC approach (in a 48-hour period) showed an improvement of approximately 72% and approximately 84% (see figures 7 and 8)

2. Rover position performance
   During a 48-hour period, all Rovers that connected to a processor (either Network or RTXNet) showed performance improvements if DSC has been enabled (see Table 1). The artificial position bias of the network had no influence on the position accuracy. With DSC enabled, the performance of the Network Processor and the RTXNet Processor show similar results.

Finally, it can be said, that the influence of sudden or constant position offsets on the performance of Network-RTK has been removed by the introduction of "Dynamic Station Coordinates". Ionospheric and

tropospheric estimates will no longer contain the influence of position errors, which then reduces the interpolation error seen by Rovers in the field.

To be able to use Dynamic Station Coordinates, the Trimble RTX App must be licensed. In the properties of the Device Manager module, enable the setting "Compute dynamic station coordinates".

The GNSS Receiver module shows information about the dynamic station coordinate in a separate tab. It displays the current status, including the statistical precision of the calculation result and offsets to the entered reference station coordinates.

The Network Processor, the RTXNet Processor and the Atmosphere Watch module automatically make use of the dynamic station coordinates when they are available.