WHITE PAPER

SUPPORT OF NETWORK FORMATS BY TRIMBLE GPSNET NETWORK RTK SOLUTION

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STATUS

The Trimble® GPSNet™ network RTK solution was first introduced in 1999. Today, Trimble is the network RTK solutions leader with over six years of global experience with network RTK commissioning and operation. Currently, more than 1800 reference stations are operating in networks in more than 29 countries using the Trimble GPSNet solution. The Trimble network RTK solution has benefited from experience gained over the years, and today the GPSNet solution is the most complete and reliable solution available for the operation of RTK networks. The Trimble solution has demonstrated continuous 24/7 operations providing the required reliability to our RTK service provider customers and their survey customers, who rely on RTK service in the field. The GPSNet solution's scalability and ability to run as a multi-server system enables it to serve an unlimited number of reference stations and users in the field. Using GPSNet, our customers operate networks as small as 4 stations up to as large as 400 stations.

Network RTK providers are operating GPSNet systems in countries across the globe on various continents, examples include: Germany, Austria, Switzerland, USA (including Alaska), Canada, Norway, Sweden, Finland, Denmark, Belgium, France, Spain, Italy, United Kingdom, Netherlands, Poland, Czech Republic, Slovenia, Serbia, New Zealand, Australia, China, Malaysia, Taiwan, Korea, and Japan.

The GPSNet software provides interfaces to geodetic dual-frequency GPS receivers of all major manufacturers, supports all industry standards including RTCM, CMR and NTRIP (for distribution of data via the Internet). Detailed information on the functionality available in GPSNet is provided in the users' manual.

DATA PROCESSING IN GPSNET

Data processing in GPSNet uses a mathematically optimal Kalman filter processing of all network reference stations and modeling of all relevant error sources, including ionospheric and tropospheric effects, orbit and clock errors, multipath, and reference station receiver noise. This central network processing computes the full state vector by describing all the error sources mentioned above with an update rate of 1 Hz and describes the effects via an optimum filter in a mathematically rigorous way (Figure 3). The approach makes use of the Trimble patented FAMCAR (Factorized Multi-Carrier Ambiguity Resolution) methodology. Using this approach to set up the Kalman filter, GPSNet is today able to process 50 reference stations on a single PC server. Larger networks are operated by multi-server solutions.

The state vector elements in the Kalman filter setup describe all the relevant error sources mentioned above. The optimum way to perform differential GPS would be to transfer this state to the rover and consider it with the rover position estimator. However, it is impossible for rover receivers today to use this kind of information directly. This is why the information has to be translated to a data protocol, which the majority of rovers understand, (i.e. the CMR, RTCM 2.x or 3.0 formats for VRS, the RTCM 2.3 format for FKP [described below]) or in the future the proposed RTCM 3.0 network messages.

VIRTUAL REFERENCE STATION (VRS)

The Trimble VRS™ (Virtual Reference Station) technique uses the complex filter state model for the complete network to compute a virtual reference station dataset (Figure 3) at a location near the rover. Today, more than 95% of the network RTK installations are using the VRS technique to transport the correction stream in standardized formats (RTCM 2.3, RTCM 3.0 or CMR) from the server to the field user. All major geodetic receiver manufacturers support these formats. In addition to the compatibility with all modern geodetic rover receiver types, the VRS technique has an advantage in that the server, using the latest model for all error sources, can continuously optimize the correction stream for each rover position. Since these error models are updated every second on a continuous 24/7 basis, every rover connecting into the system benefits from the optimal model immediately after a connection with the server is established. The VRS method requires bidirectional communication, which is available via GSM, GPRS and other cellphone-based data transmission methods. Today, more than 99% of the worldwide network RTK installations are using bidirectional communication technologies. In GPSNet, bidirectional communication also provides the ability for user access control and user accounting. However, GPSNet is not limited to bidirectional communication—users can also be provided services in multiple broadcast modes.

LINEAR AREA CORRECTION PARAMETERS (FKP)

A few years ago, the SAPOS (Satellite Positioning) community in Germany introduced a method for broadcasting network correction streams called "FKP." The acronym FKP stands for the German word "Flächenkorrekturparameter," which means area correction parameters. Within SAPOS, the providers agreed to standardize on RTCM 2.3 with a proprietary extension via a type 59 message. This additional message describes the linear ionospheric and geometric correction around a physical reference station. The linear corrections are derived from a network server using multiple reference stations. As outlined in Figure 3, GPSNet derives linear approximations from the complex filter state vector for the ionospheric and geometric effects. These linear parameters describe changes in the effects in the North-South and East-West directions. Since using a linear model is a very simplified method, the FKP parameters can only be used for a very limited area surrounding a single reference station.

Today, less than 5 % of the worldwide network RTK installations are using the FKP method. Even within the SAPOS community, the method of choice for most of the users is VRS. While FKP was designed for use in a broadcast mode, most of the installations are using it in bidirectional mode with GSM and GPRS. This is due mainly to the advantages in larger networks of the VRS technique automatically choosing the nearest reference station. As mentioned above, the VRS technique also has an added benefit in that bidirectional communications allow user access control and user accounting.

COMPATIBILITY WITH INDUSTRY STANDARDS AND ROVERS

VRS and FKP messages are used in conjunction with the RTCM 2.3, RTCM 3.0 and CMR industry standardized formats. Both methods use a special message to indicate to the rover that the data is derived from a network server and to provide additional information on ionospheric and geometric error components in the area near the rover location. These messages, and their implementation in RTCM 2.3, were communicated to all rover receiver manufacturers. As a result, all the major geodetic receiver manufacturers are providing rover solutions compatible with the VRS and FKP data formats. While this extra message is defined for FKP in RTCM 2.3 only, this extra message is available in RTCM 2.3, RTCM 3.0 and CMR for the VRS technique within GPSNet. Looking back at more than six years of experience with the VRS data format, we can state that today all GPS survey manufacturers provide rover solutions compatible with the Trimble VRS data stream.

RTCM NETWORK PROPOSAL

While the VRS method is the most common technique used worldwide, the RTCM committee is currently discussing a network proposal for broadcast transmission of network RTK corrections that will be useful with radio systems and Internet-based multicast solutions. Trimble is an active member in the RTCM Network Working Group and has contributed significantly to this format proposal. The proposal is to extend the existing RTCM 3.0 standard with additional messages for up to 31 auxiliary stations. The RTCM committee has not finalized and approved the proposed message formats; discussions continue, and rover compatibility tests by the companies participating in the RTCM committee are currently being performed. Because the RTCM committee has not finalized and released the format, Trimble has not released any network RTK server or rover supporting the proposed format. Trimble's strategy is to support standard formats that have been approved and released by the RTCM committee that add additional value and reliability to our customers while maintaining compatibility with other manufacturers.

While the RTCM 3.0 Network Proposal holds the promise of providing an improved broadcast solution for network RTK, it could also be applied to GSM and GPRS solutions. However, the required bandwidth for the RTCM 3.0 Network Proposal is much higher than for the VRS solution. As an example: With 12 visible satellites the VRS method, based on RTCM 3.0, currently requires a bandwidth of 2742 bits per second while the RTCM 3.0 Network Proposal requires 9961 bytes for an 8-station network and 34712 bits for a 32-station network. To achieve comparable performance to VRS, these bandwidths are required with an update rate of 1 Hz for the master station and the network corrections. While a lower update rate for the network corrections will lead to a lower bandwidth requirement, it will also compromise the position solution due to the introduction of additional biases. A GSM solution limited to 9600 baud is not suited to an 8-station network if an update rate of 1 Hz for all data is desired. GPRS does not have this restriction but even in the GPRS case it is desirable to provide smaller packets similar in size to those available via VRS in order to increase the reliability and timely packet throughput via the Internet/GPRS system.

Network format	8 Stations/ 12 satellites	32 Stations/ 12 satellites
VRS RTCM 2.3	6845 bps	6845 bps
VRS RTCM 3.0	2742 bps	2742 bps
SAPOS FKP	6850 bps	6850 bps
RTCM Network Proposal	9961 bps	34712 bps

Table 1: Data bandwidth requirements for different network formats

In the RTCM 3.0 Network Proposal case, if an update rate of 1 Hz for all data is desired to achieve optimal rover performance (as is the case using the VRS technique), sub-networks of not more than 7 stations in one data stream will be required in order to keep the amount of data transmitted to the rover reasonable. This will allow the user to keep the amount of data below 9600 bits per second and thus will work with most radio systems as well as GSM. However, let's assume that the complete network comprises 50 stations, which in our experience is an example of a typical medium sized network our customers are operating today. In this case, we expect that a provider using the RTCM 3.0 Network Proposal will need to set up approximately 16 data streams to cover the complete network. This estimate is derived from the fact that the provider will have to work with overlapping stations. Therefore, we must assume that 4 of the 7 stations will need to be overlapping with one of the other sub-networks (Figure 1). If the provider now chooses to use GSM, GPRS, or a unidirectional radio system, it will be necessary to relate the user to the correct data stream based upon which sub-network the user is located within. In order to do this the provider can offer 16 different dial-in numbers or GPRS mount points, or 16 radio frequencies and let the field user decide which data stream to use. Alternatively, it could be handled automatically in the server but then the rover has to provide its approximate position via bidirectional communication. As in the VRS case, kinematic users in a 50-station network using the RTCM 3.0 Network Proposal will also experience a data stream switch once they move from one sub-network area to the next.

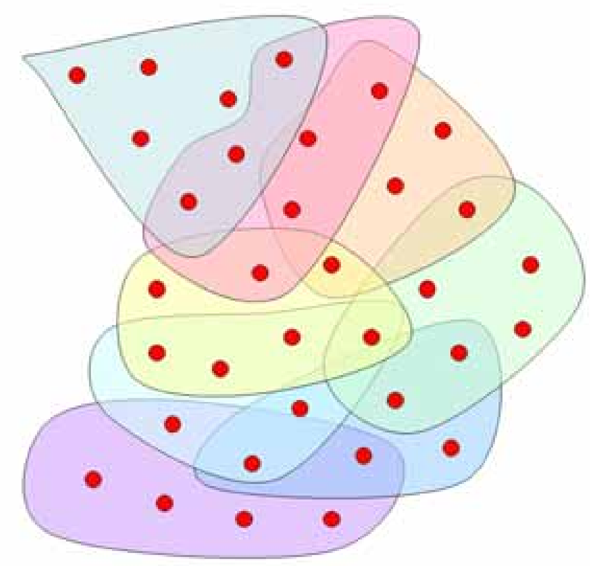

Figure 1: Example network with 32 stations and 8 sub-networks to support the RTCM network proposal with 1 Hz update rate

The RTCM 3.0 Network Proposal does not make use of the complete filter state generated in the network server. It actually uses only the ambiguities derived in the server and subtracts them from the carrier phase measurements. In other words, the RTCM Network Proposal is designed to transfer the code and carrier phase data of the master station and the carrier phase data for the auxiliary stations and removes the ambiguities beforehand (Figure 3). The rover receives these data and can then:

- Just do a simple interpolation of the ionospheric and geometric effects

- Generate a more complex model for all the error sources similar to what the network server had done before the network information was translated into the RTCM 3.0 Network Proposal format

One of the basic ideas of the RTCM 3.0 Network Proposal format is to transfer the measurement data for a sub-network in a compressed way to the rover and allow the rover to do the network calculations for the different error sources. However, one drawback of this is that the network proposal will usually only allow the transfer of a subset of the complete network. The other drawback of the RTCM 3.0 Network Proposal is that it only provides a snapshot of the ionospheric and geometric errors for a given time. Directly after connecting to the server data stream, the rover does not have any historical information on the systematic effects. However, ionospheric and especially tropospheric models need time to calculate the state parameters as they build up and converge. To ascertain good model accuracy, it might take 15 minutes or more before the models can actually predict these systemic errors with acceptable assurance. In the VRS case, the rover does not have to deal with the build up of these models. The models are built up on a continuous basis in the server, and therefore the rover has access to these precise models directly after connecting to the server. Using the Trimble VRS approach the rover user can be assured that the most up to date and best models available for all ionospheric, geometric and orbital errors are used for each rover's VRS data stream.

Other drawbacks of the RTCM 3.0 Network Proposal, that can influence rover-positioning performance are:

- The RTCM 3.0 Network Proposal transmits only observation differences and requires that the ambiguities in the network be fixed. If the ambiguities cannot be fixed and the RTCM 3.0 Network Proposal format is used in broadcast mode, the rover may encounter situations in which it receives the master station data only, which could be 300 km away. In a unidirectional system there is no fallback mechanism as is the case in a bidirectional system like the VRS approach. In VRS mode, if there is a network ambiguity fixing failure, GPSNet will always send the unmodeled data stream for the nearest reference station. However, the nearest station will in most cases be less than 30 km away from the rover while in case of the RTCM 3.0 Network Proposal formats covering large network areas the master station could be very far from the rover.
- When working with reduced update rates (like 10 seconds for example) for the network corrections the RTCM 3.0 Network Proposal solution is compromised since this latency will induce biases in the correction stream for the rover. This is especially true in situations when the server is trying to distribute data load over time. An update

interval of 10 seconds will effectively lead to maximum latencies of 20 seconds for the rover.

- The RTCM 3.0 Network Proposal requires that the master station track the same satellites as the rover. If the master station is far away this might not necessarily be the case. In typical network configurations with network extents of 300 km, elevation angles will be different by up to 4°. Depending on a given satellite's orbit it may take up to 30 minutes before a satellite has risen from 6° to 10° in elevation. The rover user will therefore find situations in which the master station does not track a particular satellite yet and therefore the satellite cannot be used in the rover solution. Only creating smaller sub-networks can solve this problem when using the RTCM 3.0 Network Proposal.

Due to the continuous update of all the error states and models, Trimble GPSNet is able to perform integrity checks and generate integrity parameters with an update rate of 1Hz. This integrity monitoring ensures a very high level of quality in the network service from all RTK service providers using GPSNet. An RTK field user benefits from this integrity monitoring directly after dial-in or connection.

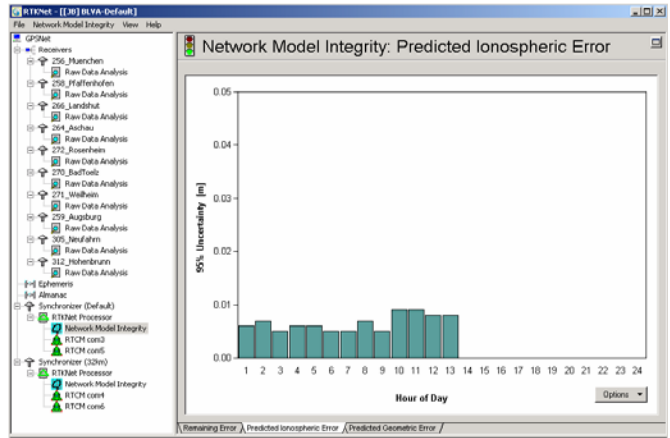

Figure 2: Example of integrity monitoring features in GPSNet - ionospheric residual errors in network area

GSM/GPRS COSTS

As described above, the RTCM 3.0 Network Proposal will increase the required bandwidth for data transmission. In the GPRS case this will also lead to higher costs in countries without a GPRS flat rate because the GPRS usage is charged based on the amount of bytes transferred. In Germany, the use of GSM communication currently costs approximately 0.15 € per minute while the GPRS data transfer costs for one provider are 1.84 € per MB. If we assume that a user is working 8 hours per day and 20 days per month the monthly costs will be approximately:

1. 1440 € in the GSM case
2. 420 € in the GPRS case using VRS in connection with the RTCM 3.0 format
3. 1270 € in the GPRS case using a 7 station network and the RTCM 3.0 Network Proposal

4. 4636 € in the GPRS case using a 32 station network and the RTCM 3.0 Network Proposal

Please note that in calculations 3 and 4 above we are assuming an update rate for all data of 1 Hz in order to make the comparison comparable with the VRS method. As we can easily see, the VRS method using the RTCM 3.0 format leads to much lower costs and far greater bandwidth efficiencies than in the other cases. The Trimble method "RTK-on-Demand," that allows the control of RTCM data transmission from the rover automatically, will lead to an even lower cost. This patented Trimble method reduces the data transmission load dramatically by transmitting data only when required for the rover performance. For example, when observing static points no data is transferred from the server while moving from one point to the next: The server starts to transmit the data again once the user has placed the antenna pole over the new survey mark.

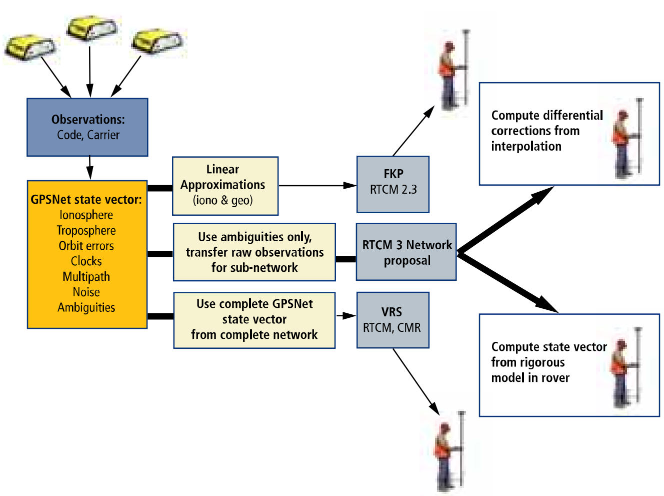

Figure 3: Network correction flow from reference stations via the GPSNet server to the rover

SUMMARY

The RTCM 3.0 Network Proposal is another approach to broadcast network RTK rather than a significant step forward in network RTK technology. Once the RTCM Committee releases the format, Trimble is committed to supporting it. The RTCM 3.0 Network Proposal holds promise for broadcast solutions like radio systems or Internet multicast solutions. It might even be used in dial-in connections with bidirectional communications like GSM or GPRS. However, in our opinion, the preferred method remains VRS and bidirectional communication due these approaches' lower data bandwidth requirements, and the fact that Trimble VRS allows the server to predict the network errors at the rover location from a complex physical model using the full reference station network information. A method based on the RTCM 3.0 Network Proposal can only use the data received at the rover, which will be limited with respect to information from the past and with respect to the number of reference stations.