Real-time RTK messages for permanent reference station applications standardized by RTCM

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Background

Over the last few years, permanent reference station installations have emerged in many countries. These installations allow for roving GPS users in the field to achieve centimeter accuracies without the need of setting up a GPS reference station on a known station.

This is quite appealing, since in areas with considerable GPS surveying activity, a number of users might share the infrastructure and the associated costs. Some of the installations are operated by companies and provide a service to the surveying community. Installations can be just single reference stations, a number of single reference stations, or networking reference stations. A single reference station set-up within up to 20-30 km is typically required if a user is operating in baseline mode. Otherwise the performance, accuracy, and with some systems the reliability of user's RTK is degraded.

The integration of several reference stations into a combined network provides benefits for the user by improving the accuracy and increasing the overall user system performance. For the reference station operator, networking reduces the number of stations that are needed to provide a given level of accuracy to the rover users. These permanent reference station networks are requiring real-time communication to a networking computation center and real-time estimation of biases between reference stations.

A key factor of success is the distribution of the information generated within the networking computation center to the roving user in the field. Some of the installations are relying on proprietary computation algorithms and possibly formats and restricting themselves with the field equipment. However, in general it is in the interest of service providers to supply the service for more than a single type of RTK field equipment. Therefore, the detailed understanding of the supplied information such as applied corrections or the way of processing is absolutely mandatory.

Today, installations are supplying the information basically in two ways: the so-called FKP-approach (FKP stands for the German word of spatial correction parameter) and the VRS approach (Virtual Reference Station). Both approaches deliver observations that are supposed to be operational with modern RTK equipment. However, as noted above, the ways the computational algorithms running at the networking computation center are proprietary. Optimal interoperability is not guaranteed, since the definition and an interface mechanism is missing. While the roving user equipment might work optimally with one vendor's networking software providing a service, it might have degraded performance with another vendor's software.

Independent RTCM Format

Traditionally, the communication interface between different manufacturer's GNSS equipment is the manufacturer independent RTCM format, which is jointly defined in a committee and all manufacturers have the possibility to participate in the definition discussions. Networking services based on either FKP or VRS approaches are providing the observations via the RTCM standard, but are basically operating in a mode not defined in the standard document and/or disseminating additional information in a proprietary message. RTCM delivers a container (message type 59) for proprietary information, but the content is not specified in the standard.

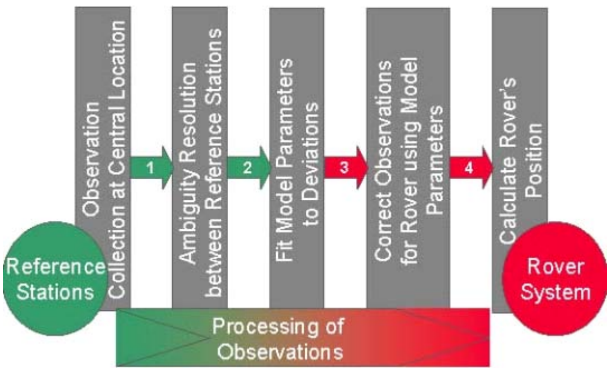

Fig. 1: Schematic Sequence of Processing

Figure 1 shows the schematic sequence of operations and calculations required until a rover's position has been calculated. Several steps are distinguishable and are realized in one way or another in all environments where several permanent reference stations are providing their observations for a combined rover solution. In principle, the best approach would be to run the full calculation for the rover's position in one place, either the networking software or the rover's firmware. The whole process can then be optimized for performance and reliability. Only when all computations are completed in one location do the developers have the full knowledge of the applied models and bias estimations within the software. Similar computational steps and interfaces have been described already in WANNINGER (2004).

However, the current networking approaches are distributing the principle calculations between the software of the

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network and the rover. The arrows, 1 through 4, indicate possible interfaces that could be utilized for the information transmission from the reference station network to the roving user system. It should be mentioned that as long as calculation steps are performed within the same software, these steps can be combined into one step. This is actually done in some approaches. Some of the processing steps prior to interfaces are easily described while others are quite sophisticated and need a detailed description, since each step affects the remainder of the processing chain. With the focus on interoperability between reference stations software from one manufacturer and rover firmware from another, these processing steps become very important for best rover performance in general. The first two interfaces, 1 and 2, are quite easily described. Through the first, the raw observations of all reference stations are transferred. Within the second schematic box the main calculations for fixing and removing the so-called integer ambiguities are summarized. Through the interface afterwards basically the raw observations leveled to a common integer ambiguity level are transferred to the next calculation step. The next three interfaces are carrying information modified by algorithms of the previous boxes and need detailed descriptions. In order to keep the computational burden low on the roving user system the most logical interface is 2, since the network has already resolved the integer ambiguities between reference stations. The remainder of the calculations can be optimized within one software, the roving user's firmware.

Master-Auxiliary Concept

Within RTCM Special Committee No. 104 (SC104), a Network RTK working group is developing the future standardized way of interfacing between networking reference stations and roving field users. Interface 2 as described above has been identified and proposed as the most common ground between all vendors. After the initial proposal in 2001, the Network RTK messages of RTCM are being jointly discussed with other vendors and a consensus on the concept has been reached. The basic idea of this so-called Master-Auxiliary Concept is to use one Master Reference Station and its raw data stream such as RTCM V3.0 message type 1004 (RTCM, 2004) and reduced information of other Auxiliary Reference Stations in the vicinity of the field of rover operation.

The Master-Auxiliary concept uses so-called dispersive and non-dispersive phase correction differences to compress network RTK information without the need for standardized correction models (EULER et al., 2001 and ZEBHAUSER et al., 2002).

The description of correction differences begins with the following definition of the single difference L1 phase equation $\Delta\Phi^{j}_{km,1}$ between two stations k, m and satellite j

$$\Delta\Phi^{j}_{km,1}(t) = \Delta s^{j}_{km} + \Delta\delta r^{j}_{km}(t) + c\cdot\Delta dt_{km,1} + \Delta T^{j}_{km}(t) - \frac{\Delta I^{j}_{km}(t)}{f_1^2} + \frac{c}{f_1}\cdot\Delta N^{j}_{km,1} + \Delta\varepsilon_1 \qquad \text{(Eq. 1)}$$

where

Δs^{j}_{km}	geometric range term including antenna phase centre variations which have been applied by the network processing software,
$\Delta\delta r^{j}_{km}$	broadcast orbit error,
Δdt_{km}	receiver clock error,
ΔT^{j}_{km}	tropospheric refraction error,
ΔI^{j}_{km}	frequency dependent ionospheric delay,
ΔN^{j}_{km}	frequency dependent integer ambiguity,
$\Delta\varepsilon$	frequency dependent random measurement error,
t	epoch,
c	speed of light,
f_1	frequency of L1.

An analogous equation for the L2 single difference phase equation can be written by replacing the index of the frequency dependent terms with 2.

Correction differences are formed by subtracting the ambiguity-leveled phase corrections of a designated master reference station from the equivalent corrections of the remaining, or auxiliary, reference stations in the network such that

$$\delta\Delta\Phi^{j}_{km,1} = \Delta s^{j}_{km}(t) - \Delta\Phi^{j}_{km,1}(t) + c\cdot\Delta dt_{km,1} + \frac{c}{f_1}\cdot\Delta N^{j}_{km,1} \qquad \text{(Eq. 2)}$$

The generation of the integer ambiguity level, a key feature of Master-Auxiliary concept, is detailed in EULER et al. (2001).

To further reduce the amount of data transmitted to the rover, Eq. 2 can be separated into a dispersive component, consisting mainly of ionospheric refraction, and a non-dispersive component consisting primarily of tropospheric refraction and orbit errors. The dispersive and non-dispersive correction differences are given by

$$\delta\Delta\Phi^{j,disp}_{km} = \frac{f_2^2}{f_2^2 - f_1^2}\delta\Delta\Phi^{j}_{km,1} - \frac{f_2^2}{f_2^2 - f_1^2}\delta\Delta\Phi^{j}_{km,2} \qquad \text{(Eq. 3)}$$

$$\delta\Delta\Phi^{j,non-disp}_{km} = \frac{f_1^2}{f_1^2 - f_2^2}\delta\Delta\Phi^{j}_{km,1} - \frac{f_2^2}{f_1^2 - f_2^2}\delta\Delta\Phi^{j}_{km,2} \qquad \text{(Eq. 4)}$$

This alternate representation of the correction differences has some specific benefits. Unlike the correction differences described in Eq. 2, the dispersive and non-dispersive components vary at different rates. In general, non-dispersive errors change slowly over time, while dispersive errors vary more rapidly, especially in times of high ionospheric activity. Therefore, optimizing the transmission rates of the dispersive and non-dispersive components can maximize data-link throughput.

In addition to the correction differences, the raw carrier phase information for the master reference station, described via RTCM V3.0 standard messages (RTCM, 2004), must also be streamed to the rover. Using the phase data of the master station and the correction differences, the rover can re-assemble and apply the raw phase information of the auxiliary stations in conventional baseline processing schemes. Alternatively, optimal correction differences can be interpolated for any position in the network and used to correct rover data. Interpolation of the correction differences is possible because they share a common integer ambiguity level. Since the raw observations of the master reference station are being part of the disseminated data stream, equipment without knowledge how to use the network RTK can also operate in a normal baseline mode.

Network – Subnetworks

Shown in figure 2 is the main aim of permanent reference station network software: the collection of data at a central location and the elimination of integer ambiguities between the reference stations. Many different interpretations of the term network are possible. The following description of network and subnetwork are based on the current RTCM definitions. A network is defined as the total structure of reference stations to be brought to the same ambiguity level in a consistent solution. If the overall assembly of the reference stations does not allow a consistent solution (all reference station on the same ambiguity level) on a regular basis, several subnetworks with possibly inconsistent solutions have to be defined. A network shall have in general only one subnetwork. The introduced Subnetwork ID is an automatically generated number.

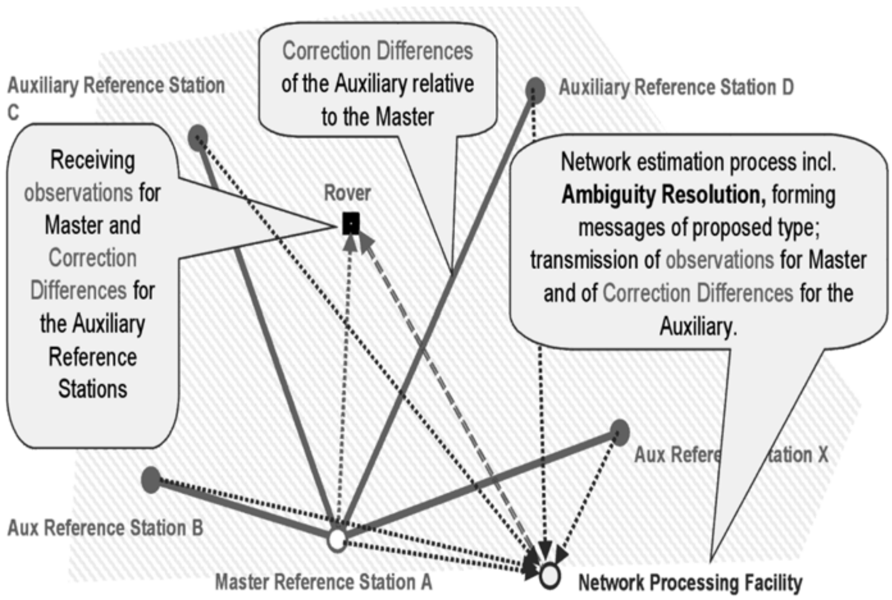

Fig.2: Master-Auxiliary Concept

All Master Reference Stations and also all involved Auxiliary Reference Stations with an identical Network ID and an identical Subnetwork ID are on the same integer ambiguity level. A common integer ambiguity level for several stations indicates for the rover operation that data information streams are interchangeable for these reference stations without reinitializing fixed rover integer ambiguities.

As soon as a reference station network solution breaks apart and a complete new set of integer ambiguities has to be calculated, the Subnetwork ID has to be increased. The increased Subnetwork ID indicates to the rover that something happened to the network integer ambiguities and the rover has to take proper action. Sometimes it might happen that a homogenous integer ambiguity level is not achievable for the entire network. This might be the case during start-up of the network solution or when reference stations crucial for the whole network are no longer available. Under these circumstances the network solution might be provided under one Network ID and each separated homogenous solution with identical integer ambiguity level will have assigned different Subnetwork IDs. The rover shall check the Subnetwork IDs in the messages provided and it will combine only information with identical Subnetwork IDs.

Throughput Requirements

The Master-Auxiliary Concept sends additional information and needs more throughput than a transmission in pure single reference station mode. In comparison to other similar methods the new RTCM V3.0 standard is quite compact. It provides a reduction of throughput of about 70% as compared to the older version 2.3. With the Master-Auxiliary Concept additional information on the network structure is transmitted which is missing in the other approaches. The throughput is varying with the chosen update rates of the different required messages. With reasonable numbers such as up to 12 visible satellites and 7 to 9 reference stations involved, the amount of data to be transferred to the field system takes between 2800 and 3200 bits per second. This number has to be compared to numbers of 4500 bits per second raw observation information transmitted for 1 reference station for 12 satellites with the more bulky RTCM standard V2.3.

Summary

Within RTCM SC104 a working group is developing a standardized method to transfer network RTK information from a processing center to a rover operating in the field. The proposed interface is currently under interoperability testing with participation of several vendors.

After the release of this standard, network RTK will be completely interoperable for the first time. Then, networking software developed by different vendors can produce identical output data streams from identical input data. Rovers in the field can operate optimally and their performance is no longer dependent on the actual networking software. The rover receives information about the distribution of reference stations and optimization can be performed in real-time by the rover system.

According to the Master-Auxiliary Concept, not only the original raw observations for the Master Station are sent to the rover but also correction differences of the Auxiliary Stations. The rover system can decide to use or to neglect the network RTK information depending on its own firmware algorithm performance.

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