LB2 and Trimble CMR+.

RTCM version 3.0 splits the L1 and L2 correction difference into dispersive and non-dispersive components: the Ionospheric Carrier Phase Correction Difference (ICPCD) and the Geometric Carrier Phase Correction Difference (GCPCD). This enables further reduction in the bandwidth by transmitting them separately, by up to 80% (O' Keefe *et al.*, 2007).

RTCM version 3.0 adopted a QualComm Cyclic Redundancy Check (CRC) at the end of a variable length message for parity check. This parity algorithm improves the efficiency for transmitting data because it only requires 24 bits of each message as opposed to six bits out of every thirty bits in RTCM version 2.3. Hence it ensures each message is independent of the others, and also reduces the bandwidth significantly. Furthermore, the algorithm improves the integrity of the message by providing protection against burst, as well as random errors with a probability of undetected error $\leq 2^{-24} = 5.96 \times 10^{-8}$ for all channel bit error probabilities ≤ 0.5. Further information can be found in the format specification of RTCM version 3.0 (RTCM, 2004a).

5.2 Message Types and Content

RTCM version 3.0 is a flexible format from an operational perspective. Message types have been organised into different groups. Different message types in each group contain similar information. Hence, message types can be mixed and there is a saving in broadcast link throughput. For example, a DGNSS service provider can select message Type 1001 from the GPS observations group for single-frequency (L1) observation with minimum bandwidth, or message Type 1004 for dual-frequency (L1 and L2). This is also true for other groups such as the stationary antenna reference point, antenna description as well as GLONASS observations. Tables 3 - 6 describe each group and the corresponding message types. Although RTCM version 3 overcame the limitations of RTCM version 2, they are not compatible.

Table 3. GPS observations (RTCM v3.0)

Type	Content
1001	L1 only GPS RTK observables
1002	Extended L1 only GPS RTK observables including satellite signal-to-noise (CNR), full milliseconds for code observations
1003	L1 and L2 GPS RTK observables
1004	Extended L1 and L2 GPS RTK observables including satellite signal-to-noise (CNR), full milliseconds for code observations

Table 4. Stationary antenna reference point (RTCM v3.0)

Type	Content
1005	Stationary RTK reference station ARP coordinates, ECEF XYZ
1006	Stationary RTK reference station ARP coordinates with Antenna Height

Table 5. Antenna description (RTCM v3.0)

Type	Content
1007	Antenna Descriptor
1008	Antenna Descriptor and Antenna Serial Number

Table 6. GLONASS observations (RTCM v3.0)

Type	Content
1009	L1-only GLONASS RTK observables
1010	L1 only GLONASS RTK observables including satellite signal-to-noise (CNR), full milliseconds for code observations
1011	GLONASS L1+L2 observations
1012	Extended L1 and L2 GLONASS RTK observables including satellite signal-to-noise (CNR), full milliseconds for code observations

6. RTCM SC104 Standard Version 3.1 and Addendums

6.1 RTCM Network-RTK Messages

The use of the network-RTK technique in place of single-base RTK increases not only inter-receiver distance but also reliability. Modelling of the systematic errors across the CORS network is the key to achieving high accuracy. There are currently three commercially available network-based solutions: FKP, VRS and MAC. FKP is a technique based upon broadcasting correction parameters from a CORS network. The SAPOS® Network system in Germany adopted this solution by customising RTCM version 2.3 Message Type 59 with proprietary extension (Wübbena and Bagge, 2006). Another technique is known as the Virtual Reference Station (VRS) (Landau *et al.,* 2002). VRS, as the name implies, creates a “virtual” reference station near the rover receiver and interpolates the corrections from the CORS measurements. The virtual measurements are then transmitted to the user, encoded in Message Types 18/19 in RTCM version 2.3, and Messages Types 1001-1004 in RTCM version 3.0.

Brown *et al*. (2005) pointed out the limitations of these approaches, and in order to overcome such limitations Leica Geosystems and Geo++ jointly proposed a new network-based RTK solution known as the Master-Auxiliary Concept (MAC) based on RTCM 3.0 network messages. Brown *et al*. (2006) demonstrated that MAC offers higher accuracy and reliability than FKP or VRS. A comparison between VRS and MAC principles, with particular consideration of the required bandwidth, is presented by Janssen (2009). RTCM version 3.1 was confirmed and released in 2006 (RTCM, 2006), and contains new messages for network operation, for the MAC and for GPS/GLONASS ephemeris data, as well as for arbitrary text messages.

Five new message types for network-RTK were defined to incorporate MAC. Table 7 lists the new messages and their contents. These messages primarily comprise compressed observation data from a CORS network which are transmitted to the rover receiver. As a result, the computational burden was moved from the network-RTK server to the rover receiver software.

Although RTCM network-RTK improved broadcast solution, the required bandwidth for the RTCM network messages is higher than that for the VRS solution. In order to achieve comparable performance to VRS, the RTCM network solution generally requires a 1 Hz update rate for the master and network corrections, although the geometric corrections can be transmitted at a lower update rate. As a result, use of GPRS is desirable over GSM due to limitation on baud rate. Trimble Navigation Ltd. (2005) and Norin *et al.* (2009) reported RTK positioning tests which compare accuracy between a VRS solution and the RTCM network-RTK solution. RTCM network-RTK message types 1014, 1015 and 1016 were used over 14 stations of the Swedish national network of permanent reference stations network (SWEPOS™). Test results indicated no accuracy performance differences between the two solutions.

Table 7. Network messages (RTCM v3.1)

Type	Content
1014	Network Auxiliary Station Data coordinate difference between one auxiliary station and the master station
1015	GPS Ionospheric Correction Differences for all satellites between the master station and one auxiliary station
1016	GPS Geometric Correction Differences for all satellites between the master station and one auxiliary station
1017	GPS Combined Geometric and Ionospheric Correction Differences for all satellites between the master station and one auxiliary station
1018	Reserved for alternative Ionospheric Correction Difference Message
1019	GPS ephemeris
1020	GLONASS ephemeris

6.2 RTCM Version 3.1 Addendums

The Addendum 1 to RTCM version 3.1 was confirmed in May 2007 (RTCM, 2007a). It introduces new message types for transformation parameters. Types 1021 - 1028 are defined for datum transformation and projections, see Table 8.

Table 8. Transformation messages (RTCM v3.1)

Type	Content
1021	Helmert / Abridged Molodenski transformation parameters
1022	Molodenski-Badekas transformation parameters
1023	Transformation residual message, ellipsoidal grid representation

Type	Content
1024	Transformation residual message, plane grid representation
1025	Projection parameters, types other than LCC2SP, OM
1026	Projection parameters, type LCC2SP (Lambert Conic Conformal)
1027	Projection parameters, type OM (Oblique Mercator)
1028	Reserved for global to plate fixed transformation

The Addendum 2 to RTCM 3.1 was released in August 2007, with the four new message types listed in Table 9. The Message Types 1030 and 1031 define additional information for network-RTK operations such as VRS, FKP and MAC. Message Types 1030 and 1031 are allocated for network residuals for GPS and GLONASS respectively. Type 1032 is similar to Message Type 1005, and provides ARP station coordinates in ECEF X, Y, Z for the base of the antenna. Type 1033 is a combined Message Types 1007 and 1008 and hence contains antenna descriptor and serial number as well as receiver descriptor and serial number.

Table 9. Other messages (RTCM v3.1)

Type	Content
1030	GPS network-RTK residuals message
1031	GLONASS network-RTK residuals message
1032	Physical reference station position message
1033	Receiver for antenna and receiver descriptor

6.3 Future Amendments of RTCM SC-104

Present RTCM SC-104 standards support both GPS and GLONASS for DGNSS and RTK operations. The modernisation of GPS will provide new signals, namely L2C and L5, and a mixture of phase measurements from different signals will be available within a few years. However, RTCM version 2.3 has limitations as far as new GNSS signals are concerned. RTCM needs extensions for the inclusion of such new signals. Support for L2 carrier phases is only available for L2P. The RTCM version 3 has a GPS L2 Code Indicator to identify C/A or L2C code under the assumption that no satellite will transmit both C/A code and L2C code signals on the L2 carrier simultaneously. Therefore RTCM version 3 can support tracking modes for L1 C/A code, L1 P(Y) code, L2 P(Y) code and L2C signals.

GALILEO signals will be available in the near future, hence an amendment will be necessary to current versions of the RTCM SC104 standards in order to incorporate new signals provided by GALILEO. RTCM SC-104 version 3 has the flexibility to accommodate GALILEO data and associated information. Klepsvik *et al*. (2004b) drew attention to the need for amendments of current DGNSS standards and proposed new GALILEO RTCM message types.

7. Usage of RTCM SC-104 Formats

A web site listing the global network of real-time GNSS NTRIP casters maintained by the