International standard GNSS real-time data formats and protocols

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International Standard GNSS Real-Time Data Formats and Protocols

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ABSTRACT

The Differential Global Navigation Satellite System (DGNSS) and Real-Time Kinematic (RTK) positioning techniques have been introduced to address the need for high accuracy real-time positioning. Transmitting corrections or raw measurements from one or more reference stations to a mobile user receiver is the key to differential positioning. Most GNSS receiver manufacturers have been developing and maintaining their own data format(s). Although a manufacturer's proprietary protocol is arguably efficient and reliable, industry standards are often required. In particular, interoperability is an issue for managing networked reference stations comprising different types and brands of GNSS receivers. Receiver Independent Exchange (RINEX) format was introduced for exchanging GNSS data with a standard file format. However, it is not applicable for real-time data transmission. The Radio Technical Commission for Maritime Services SC-104 has introduced formats and protocols that are now accepted as international standards. The data protocol has evolved over many years by incorporating new message types. On the other hand, the Networked Transport of RTCM via Internet Protocol (NTRIP) and RT-IGS protocols were developed as network transport protocols to deliver GNSS data via the internet.

This paper describes the mechanisms for real-time delivery of GNSS data in terms of transmission protocol, data format, communication link issues, message structure, data types and content between the various versions of RTCM SC-104 formats, including recent amendments. Future message amendments and protocol proposals that incorporate new signals such as from the Galileo system are also discussed. Current usage of various RTCM formats and message types are investigated and analysed.

KEYWORDS: GNSS, RTCM, NTRIP, standard, protocol

1. INTRODUCTION

Over the last several decades the Global Positioning System (GPS) has been widely used for positioning, navigation and timing, as well as for scientific and non-positioning applications. The differential GPS (DGPS) and Real-Time Kinematic (RTK) positioning techniques were introduced in order to improve accuracy by eliminating receiver independent error sources. DGPS uses signal travel time between a satellite and a receiver to compute the distance or pseudo-range, whereas RTK uses carrier phase measurements as well. Both DGPS and RTK require the broadcast of corrections from one or more reference stations located at known point(s) to mobile user receivers via a wireless communications link.

Typically, most of Global Navigation Satellite System (GNSS) receiver manufacturers develop and maintain their own data format. For example, Leica LB2, Trimble RT17 and RT27, Ashtech MBEN and PBEN, and Topcon TPS are well known proprietary formats. These are mostly encoded binary formats and are efficient in terms of bandwidth, but often require the use of mobile receiver software/hardware supplied by the relevant manufacturer as the reference receiver(s). For instance, Trimble provides the Trimble Reference Station (TRS™) software to control a Trimble GPS reference station and log data to a file. Since both hardware and software are designed and integrated by the same manufacturer, this maximises the reliability of the real-time systems (Yan, 2006).

However, "interoperability" is increasingly an issue in the case of Continuously Operating Reference Station (CORS) networks that consist of different brands and types of receivers. In order to manage a mixed pool of receivers, reference receivers are required to transmit a protocol and data format that can be accepted by any mobile user receiver. Hence an internationally accepted protocol/format is essential.

This paper will discuss international standards for real-time GNSS with a focus on the Radio Technical Commission for Maritime Services (RTCM) SC104 data formats. The RTCM SC104 2.3 (RTCM 2.3) format and RTCM SC104 3.0 (RTCM 3.0) format are compared in terms of structure and format specifications. The similarity and differences are described, and the advantages and disadvantages with respect to bandwidth and efficiency will be commented upon.

2. Exchanging GNSS Data and Service Types

There are two ways of exchanging GNSS data. Firstly, differential post-processing operations have been known since the early stage of GPS applications. The Receiver INdependent EXchange (RINEX) format was introduced by the Astronomical Institute of the University of Berne, Switzerland, in the late 1980s for exchanging GPS data in an ASCII file format for scientific and geodetic applications. RINEX was (and still is) an international standard. Most receiver manufacturers provide utilities to convert from their proprietary data format into the RINEX format. Typically, hourly or daily data are archived in RINEX file format and available from a File Transfer Protocol (FTP) server to download. There are many applications using the post-processing method with RINEX files such as surveying and GIS, atmospheric science and geophysics which requires long periods of data. However, RINEX is strictly file-based and is not applicable for real-time data transmission. There have been several revisions of RINEX with the latest, RINEX v3.01, currently before the International GNSS Service (IGS) awaiting approval.

Secondly, there are real-time protocols in both receiver proprietary formats and international standards. Although a manufacturer's proprietary format has been known to be suitable for more robust operations with between same-make receivers, industry-standard formats are required to ensure interoperability, i.e. operations between brand 'X' and 'Y' receivers.

This paper focuses on real-time data delivery protocols and standard data formats with an emphasis on the RTCM format.

3. Real-time Delivery of GNSS Data

In order to deliver GNSS information in real-time three components are necessary: transmission protocol, data format and data communications link. The transmission protocol manages data delivery across a network by providing reliable flow control mechanisms. Data format is an agreement/specification for translating transmitted bit sequences into meaningful information. The data communications link is the means of transporting information from one party to another. Generally, there are two types of data links: uni-directional and bi-directional.

3.1 Transmission Protocol

There are two standard protocols for distributing GNSS data over the internet: Networked Transport of RTCM via Internet Protocol (NTRIP) and Real-Time IGS (RTIGS). NTRIP was developed using the principles of an internet radio technology to support dissemination of GNSS data over the internet in real-time. NTRIP is a generic, stateless protocol based on the Hypertext Transfer Protocol HTTP/1.1 (Weber, 2004). A few years ago the RTCM Committee accepted NTRIP version 1.0 as a standard for packet-based communications (RTCM, 2004b). NTRIP version 1.0 utilises Transmission Control Protocol and Internet Protocol (TCP/IP) to obtain a reliable delivery of byte streams. NTRIP version 2.0 is undergoing evaluation for full HTTP compatibility and for the optional use of the User Datagram Protocol and IP (UDP/IP) in addition to TCP/IP. NTRIP can be used not only for 'carrying' RTCM format data, but also other proprietary GNSS data formats.

The Real-Time IGS Working Group introduced the RTIGS protocol for disseminating GNSS data streams over the internet. The RTIGS protocol is based on UDP/IP and uses the so-called SOC data format designed by JPL for transporting GPS observation data with minimal bandwidth. Performance analysis of both protocols has been conducted by Yan *et al*. (2009).

3.2 GNSS Data Format

The NMEA 0183 is a standard for data communication developed by the U.S. National Marine Electronics Association (NMEA) to avoid incompatibilities such as data rates and message format between marine electronic devices (Langley, 1995). Hence, NMEA is mainly used for transmission of data between a GPS/GNSS receiver and other devices. It is an ASCII format, hence data is easily readable but less compact than binary format. Although most GNSS receivers conform to output NMEA 0183 messages, these messages are limited to navigation information and contain no observation data hence do not allow for differential or RTK operation (Yan, 2006).

The Radio Technical Commission for Maritime Services (RTCM) was founded in 1947 as a U.S. State Department Advisory Committee. Currently it is an independent organisation of government agencies, manufacturers and service providers from around the world. The strong demands for real-time DGPS led to the establishment of the RTCM Special Committee 104 Differential Global Navigation Satellite Systems (RTCM SC 104) in order to standardise an industry standard format for the correction messages (Langley, 1994). The current format has become well known as RTCM version 2.x and has been updated to version 3.x. Due to an inefficient format structure RTCM version 2.x requires relatively high bandwidth. As a result it was not well suited for RTK operations, consequently Trimble Navigation developed a compact alternate data transmission format that was widely adopted as an industry standard (Talbot, 1996). The format is known as the Compact Measurement Record (CMR) and was suitable for transmitting GNSS data at a lower baud rate. CMR format was improved with less peaked throughput, and is referred to as CMR+ (Talbot, 1997). Many other GNSS receiver manufacturers implemented the CMR/CMR+ format into their products since then.

3.3 Data Communications Link

A data communications link obviously is essential for real-time relative positioning. DGPS or RTK correction data were transmitted via Very High Frequency (VHF) or Ultra High Frequency (UHF) radio signals for many years. With development of a range of wireless communication technologies, the internet is now the preferred alternative means of transmitting GPS corrections. There are many different types of wireless links available for bidirectional communications, though the main ones are the Global System for Mobile communications (GSM), General Packed Radio Service (GPRS) and Universal Mobile Telecommunications System (UMTS). Connections via GSM are typically charged by connection time, whereas GPRS is charged by the amount of download data.

4. RTCM SC-104 Standard Version 2.x

4.1 Message Structure

RTCM version 2 format design was based on the structure of the GPS Navigation Message itself. In other words, word size, format and parity algorithms are the same. The GPS Navigation Message is transmitted by a satellite on the data link at a rate of 50 Hz, with one word consisting of 30 bits. Each Telemetry Word and Handover Word is thirty bits long and it is the first and the second word in each page. Each word in each frame contains six parity bits. Similarly, RTCM version 2 messages consist of two or more thirty bit words. The first two words of each message contain header information, such as preamble, message type, station ID, etc. Among the thirty bits, 24 carry the data and 6 are allocated for parity check, and the header information is pertinent to any type of message. The size of word and the parity checking algorithm used are identical to those used for the GPS Navigation Message. Further information is available in the GPS-SPS Signal Specification available from the U.S. Coast Guard Information Service (GPS-SPS, 1995a). The message structure is illustrated in Figure 1.

Figure 1. 30 bit word structure

After the header message, there is variable length of following messages. The message length is determined by the number of data words field in the header message. The message length is defined for particular message types specified in the RTCM version 2 documents. A data link carries the information from the reference station to the rover/user receiver. Hence, the reference receiver produces the GNSS data and converts it to the appropriate data transmitter formats and modulates the data onto a transmitter carrier for broadcast to mobile user equipment. According to the format specification of the RTCM version 2.3, the American National Standards Institute (ANSI) X3.15 and X3.16 standards (ANSI X3.15-1976, ANSI X3.16-1976) for eight-bit character structure governs the serial data transfers. As a result, thirty-bit words must be represented in an eight-bit format. In RTCM version 2, a special "6 of 8" format is used; each byte contains 6 bits from the GPS word and the remaining 2 bits are set as "marking" and "spacing" respectively (1 and 0) to fill the thirty bit word format. Figure 2 shows the structure of the 6 of 8 format.

Figure 2. Five byte representation using the “6 to 8” format

The standard 8-bit byte is described in ANSI X3.16. This standard assigns the first data bit transmitted as the least significant bit, whereas the RTCM standard follows the "Most Significant Bit First Rule". This results in a "byte roll" where the order of the bits within the byte has to be reversed. Detailed information about the interface rules are defined in chapter 5 of the specification of RTCM SC104 2.3 (RTCM, 2001).

4.2 Message Types and Content

RTCM version 2.0 was defined on 1 January 1990 for pseudo-range corrections to support DGPS application with message types listed in Table 1 (RTCM, 1990). Type 1 contains information for differential corrections such as Pseudo-Range Correction (PRC) and Range-Rate Correction (RRC), Issue Of Data (IOD), and User Differential Range Error (UDRE). The Type 2 message carries delta-differential GPS corrections, i.e. the difference in the pseudo-range and range-rate corrections results in a change in satellite navigation data. Type 3 messages contain the Earth-Centred, Earth-Fixed (ECEF) location of the reference station. Type 59 is a proprietary message for transmission of any data. RTCM version 2.0 does not support information from networked reference stations, hence the company Geo++ used message Type 59 to transmit area correction parameters known by their acronym “FKP” (in German, Flächen-Korrektur-Parameter) from reference station networks. Message structure and proprietary information content for Type 59 is described in Wübbena and Bagge (2006).

In 1992, the carrier phase communications working group was established in order to revise RTCM version 2.0 standards. As a result, changes to the standards for the carrier phase data was recommended (RTCM, 1992). RTCM version 2.0 was updated to version 2.1 with RTK messages in 1994 for the carrier phase and pseudo-range transmitted as uncorrected raw measurement information (Types 18 and 19) or as corrections (Types 20 and 21) (RTCM, 1994). RTCM version 2.2 (RTCM, 1997) was released in 1998, introducing differential GLONASS corrections (Type 31). Type 31 is equivalent to the Type 1 of DGPS corrections. However, Types 18-21 are not fully compatible with the previous version. RTCM version 2.3 (RTCM, 2001) was defined in 2001 by adding more message types, such as antenna description, antenna serial number (Type 23) and coordinates of the antenna reference point (ARP) at the reference station (ECEF X, Y, Z), and optionally antenna height, (Type 24). In addition several new messages were introduced to improve RTK, radio-beacon broadcasts and the use of Loran-C, etc.

Table 1. Basic message types for RTCM version 2.0

Type	Content
1	Differential GPS corrections (pseudo-range and velocity, maximum 12 satellites)
2	Pseudo-range corrections, referring to previous orbit data records (maximum 12 satellites)
3	Reference station coordinates (ECEF X, Y, Z)
6	Null message, used as filler record during time-outs
16	Special message (maximum allowed length 90 characters ASCII text)
59	Proprietary messages, for transmission of any required data

RTCM version 2.3 has been adopted by all commercial, off-the-shelf receivers and is still widely used for DGPS or single-base RTK operations. However, there are limitations with RTCM SC104 version 2.3. First of all, each word contains 24 bits data and 6 bits of parity. This 30 bit word structure wastes bandwidth due to inefficient encoding of the messages. Secondly, the parity calculation includes bits from the previous word. As a result each message is not independent from one word to the next. Finally, the RTCM version 2.3 scheme is not flexible enough to accommodate new signals such as the GPS L2C and L5, and other future GNSS systems such as GALILEO and Compass. Furthermore, new network-RTK concepts were not able to be implemented using the RTCM version 2.3 format.

5. RTCM SC-104 Standard Version 3.0

5.1 Message Structure

RTCM SC-104 introduced a new standard known as RTCM SC104 version 3.0 (or simply

RTCM version 3) in order to overcome these drawbacks. Hence RTCM version 3.0 is designed to improve RTK operations and to support network-RTK. Its enhanced structure benefits RTK operations due to efficient bandwidth use during broadcast.

RTCM version 3.0 addressed earlier limitations by restructuring the format. All RTCM 3.0 messages start with an 8-bit fixed sequence followed by 6 reserved bits. Each message length is variable and depends on the type of message. The structure of RTCM 3 messages is indicated in Table 2.

Table 2. RTCM version 3 frame structure

Preamble	Reserved	Message Length	Variable Length Data Message	CRC
8 bits	6 bits	10 bits	Variable length, integer number of bytes	24 bits

RTCM Message Type 1003 is a dual-frequency GPS RTK message based on raw pseudo-range and carrier phase measurements. RTCM Message Type 1003 consists of 64 bits of GPS RTK header information and 101 bits per satellite of body. Fill bits must be used to complete the last byte at the end of the message data before the CRC in order to maintain the last byte boundary. With an assumption that there are 10 satellites available at a particular epoch, the total number of bits to be transmitted can be calculated as:

8 bits (preamble) + 6 bits (reserved) + 10 bits (message length) + 64 bits (header)
+ 10 satellites × 101 bits (body) + 6 bits (fill bits) + 24 bits (CRC parity) = 1128 bits
= 141 bytes

Therefore, 141 bytes are necessary to transmit a GPS RTK message for 10 satellites. In comparison, RTCM version 2.3 Message Type 18 contains the L1, L2 carrier phase measurements and Message Type 19 contains the pseudo-range measurements. Each message type has two words of header information, one word contains GPS time of measurement and each message contains 2 words per satellite for corrections. Under the same assumption of 10 satellites, the total number of bits to be transmitted with RTCM version 2.3 is computed as:

Message Type 18 for carrier phase for L1:
2 words (header) + 1 word (measurement time) + 2 words × 10 satellites = 690 bits
Message Type 19 for pseudo-range for CA code:
2 words (header) + 1 word (measurement time) + 2 words × 10 satellites = 690 bits
Message Type 18 for carrier phase for L2:
2 words (header) + 1 word (measurement time) + 2 words × 10 satellites = 690 bits
Message Type 19 for pseudo-range for P code:
2 words (header) + 1 word (measurement time) + 2 words × 10 satellites = 690 bits

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= 2760 bits
= 345 bytes

This example clearly shows that the RTCM version 3.0 format has reduced bandwidth requirements significantly compared to that of RTCM version 2. More bandwidth and efficiency comparison between Type 1003 and 18/19 are given by Lin (2006). According to Yan (2006), RTCM version 3 also uses less bandwidth than proprietary formats such as Leica

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

German national mapping agency, the Federal Agency for Cartography and Geodesy (BKG) with the support of RTCM's SC104 NTRIP Working Group, shows the current status of NTRIP casters on the Internet (Stream Table of Global NTRIP Broadcasters, 2009). Based on the list, the pattern of current RTCM format usage was analysed. According to the list, internationally there are 2030 streams that broadcast GNSS data via the Internet. 1027 streams are identified as RTCM version 2.x (x: 1, 2, 3 or 4), 973 streams are RTCM version 3.x (x: 0 or 1), and there are 30 streams categorised as RTCM SAPOS which use message type 59 for FKP corrections. Currently, different types of real-time differential services, such as DGPS, single-base RTK and network-RTK, are provided by 98 agencies from 38 different counties. 1521 streams are servicing single-base RTK or DGPS, whereas 509 streams are providing network-RTK corrections. Figure 3 illustrates the distribution of RTCM SC104 format usage.

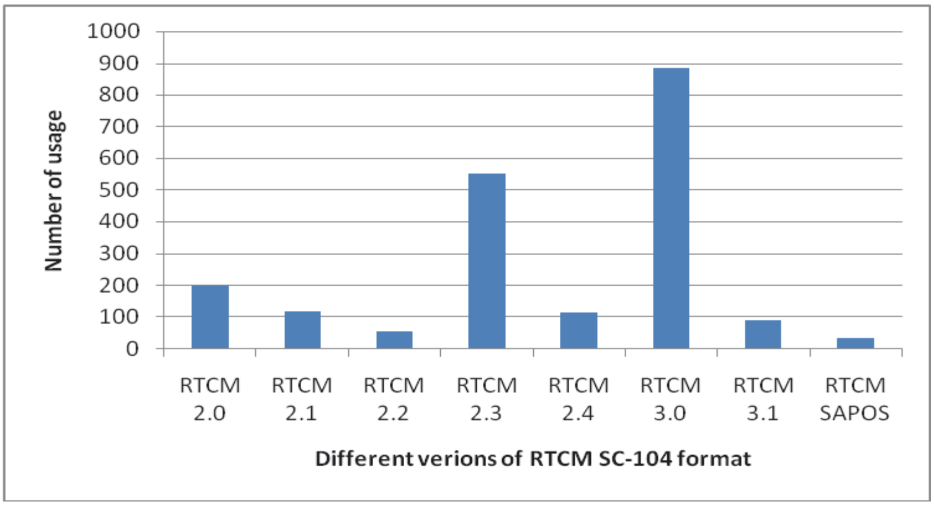

Figure 3. Distribution of RTCM SC-104 versions broadcast via NTRIP (July 2009) (Stream Table of Global NTRIP Broadcasters, 2009)

RTCM version 3.0 is the most popular format at the moment, but it is noticeable that RTCM version 2 is still widely used in many places. Although RTCM version 3 has significant advantages compared to RTCM version 2, a complete replacement may require an adaptation period to ease in the new standard. For instance, most maritime DGNSS applications use the RTCM SC104 format, such as the public DGNSS services by maritime radio beacons coordinated by the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) as well as the Automatic Identification System (AIS) DGNSS service. Both services will use the RTCM version 2 formats for the next 5-6 years due to International Maritime Organization (IMO) regulations (IMO Resolution A.953(23) (2003) on World Wide Radionavigation Systems) which requires an adequate notice to promulgate (Klepsvik *et al*., 2004a). However, the commercial DGNSS services are likely to replace RTCM version 2 with RTCM version 3.0 in the near future because of economic advantages and increased flexibility.

Figure 4 illustrates the distribution of RTCM SC-104 version 2.x (x: 0, 1, 2, 3, 4) message types, as derived from an analysis of the NTRIP list. Message Types 1 and 3 are the most widely used types. Together with Type 2 for delta differential GPS corrections and Type 31 which is the differential GLONASS correction message, RTCM 2.x is mostly used for DGNSS services at the moment. Types 18/19 and 20/21 are uncorrected raw measurements and corrections of carrier phase and pseudo-range, respectively. These message types support RTK operations. Types 22 - 24 define reference stations parameters and antenna types. Type

59 is mainly used in Germany and Spain for FKP-supported services.

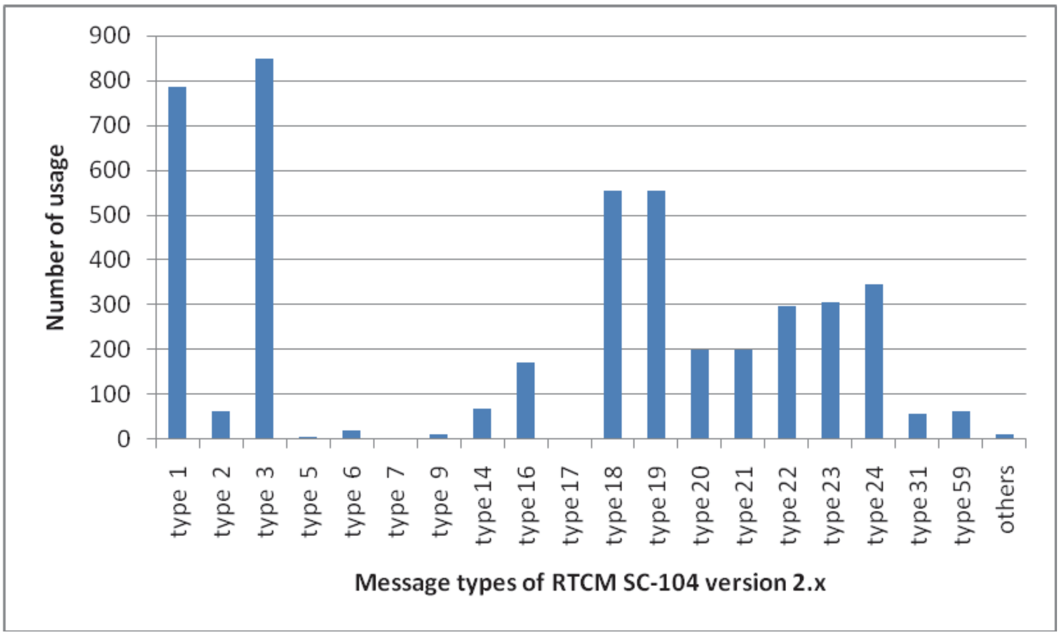

Figure 4. Distribution of RTCM SC-104 version 2.x message types broadcast via NTRIP (July 2009) (Stream Table of Global NTRIP Broadcasters, 2009)

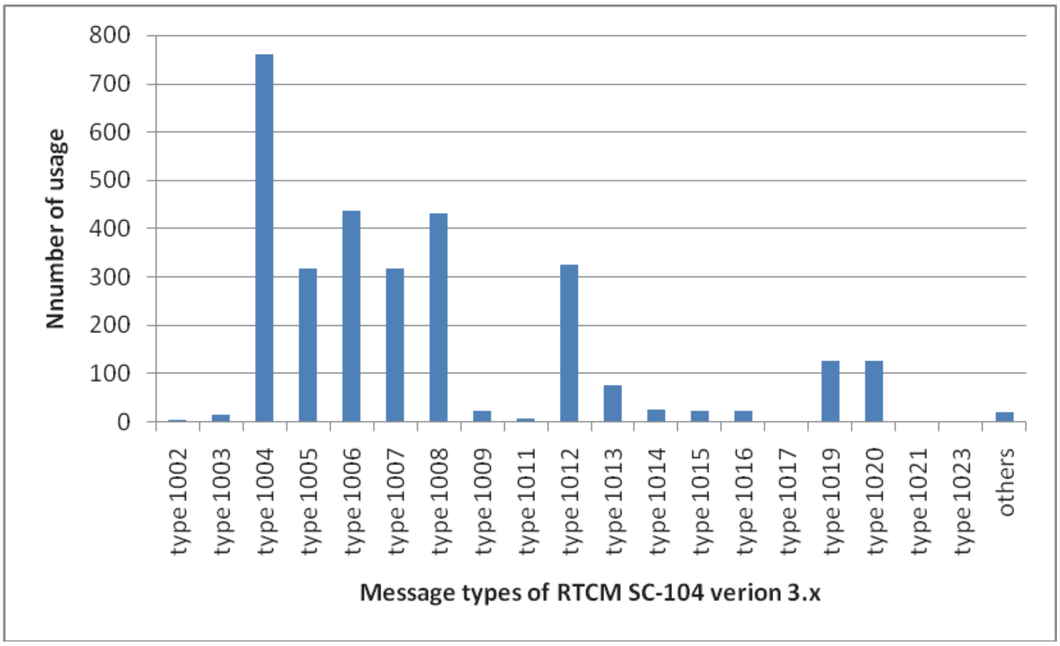

Figure 5. Distribution of RTCM SC-104 version 3.x message types broadcast via NTRIP (July 2009) (Stream Table of Global NTRIP Broadcasters, 2009)

Figure 5 illustrates the variety of RTCM SC-104 version 3.x (x: 0, 1) message types that are broadcast. Type 1004 is the most frequently used format. Types 1005/1006 and 1007/1008 are designed for stationary RTK reference station antenna reference point coordinates and antenna descriptor messages, respectively. Message Type 1012, which defines GLONASS RTK observables, is also widely used. Message Types 1019 and 1020 include GPS and

GLONASS ephemerides, respectively.

8. CONCLUDING REMARKS

International real-time GNSS standard formats were discussed in general, and the RTCM scheme in particular. Considerations for real time delivery of GNSS data include transmission protocol, data format and communications link. The network transport protocol NTRIP was briefly introduced. An overview of the different RTCM formats was given. Format specification and structure of both RTCM SC104 version 2 and version 3 were discussed, and comparisons were made in terms of throughput, bandwidth and flexibility. The drawbacks of RTCM SC104 version 2 were mentioned and improvements made in RTCM SC104 version 3 were highlighted. The message contents of RTCM SC104 version 3 were discussed, and recent amendments were described.

RTCM is an industry standard format for GNSS data which enhance interoperability between different types and brands of GNSS receivers. However, RTCM version 2.3 was not widely used for RTK operations due to its inefficient encoding of messages and limited options. RTCM version 3 has been developed in order to overcome the limitations of version 2.3. RTCM version 3 is more flexible and efficient in terms of structure, throughput and compatibility. Further amendments will be made to incorporate the GALILEO and new GNSS signals in future versions of the RTCM SC104 standards.

The distribution of RTCM SC-104 format data streams was investigated based on the most recent list of global real-time GNSS NTRIP casters maintained by the BKG. It shows that RTCM version 2 is still mainly used for pseudo-range-based DGNSS services, whereas RTCM version 3 is widely used for carrier phase-based RTK services.

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