Real-Time Data Flow and Product Generation for GNSS

Ronald J. Muellerschoen
rjm@mailhost4.jpl.nasa.gov

Jet Propulsion Laboratory

California Institute of Technology

Mark Caissy
caissy@NRCan.gc.ca

Natural Resources Canada

Abstract

The last IGS workshop with the theme "Towards Real-time" resulted in the design of a prototype for real-time data and sharing within the IGS. A prototype real-time network is being established that will serve as a test bed for real-time activities within the IGS. We review developments of the prototype and discuss some of the existing methods and related products of real-time GNSS systems. Recommendations are made concerning real-time data distribution and product generation.

Real-Time Data

The fundamental packet delivery service of the TCP/IP family of protocols is connectionless. IP is a best effort network protocol that provides no guarantee of packet delivery. Within the network layer lie the two dominant transport protocols, which provide both connectionless and connection-oriented services. These of course are UDP and TCP, respectively. TCP is used when reliability is more important than speed. It requires acknowledgements of packet arrivals, and retransmission of lost packets. On the other hand UDP is used when speed is more important than reliability. Because UDP is not a guaranteed service, it is more suitable for real-time services. Both Natural Resources Canada's (NRCan) and the Jet Propulsion Laboratory's (JPL) GPS groups recognized early the advantages of UDP for data flow and both implemented data flow technologies that extensively use the UDP protocol.

The Real-Time Working Group (RTWG) has proposed a common data format and method that should allow for universal access to the data streams from accumulating organizations. The format includes 4 basic message types: 1.) GPS observations 2.) GPS ephemeris 3.) Meteorological observations and 4.) a novel message that reports station configuration changes. Each message contains a uniform 11-byte header, as follows:

type	variable	meaning
unsigned short	rec_id	indicates one of the 4 record type2
unsigned short	sta_id	unique station id
unsigned long	GPSTime	seconds past 6-Jan-1980
unsigned short	num_bytes	number of bytes in this message type
unsigned char	IODS	station configuration flag

The payload specific data then follows the header. The GPS observation payload is as follows:

type	variable	meaning
unsigned char	num_obs	number of GPS observations
unsigned short	GPSMilli	millisecs past the GPSTime
short	StaClock	station clock in 10*meters
21 bytes per GPS observation in JPL soc format		

For a receiver tracking 10 GPS satellites, the number of bytes in this format would then be 226 (16 + 21*10). NRCan's udpRelay additionally layers this with a 24-byte header and appends a 16-byte Message Authentication Code (MAC).

Differential Systems

GPS differential systems fall into one of three categories: measurement domain, position domain, and state-space domain [Abousalem, 1996]. Measurement domain algorithms provide the user with corrections from a reference station or a weighted average of corrections from a network of reference stations. In the position domain approach, the user computes independent positions using corrections from separate reference stations. A weighted average of these solutions is then computed. The disadvantage of both the measurement and position domain algorithms is a degradation of accuracy with distance from the network's center. In contrast, the state-space approach models and estimates real physical parameters including satellite clocks and orbits, reference station troposphere and clocks. The ionosphere delays can additionally be modeled from dual-frequency reference station data for single-frequency end users.

Penno, Whitehead, and Feller [1998] discuss the advantages;

> Advantages to using the states-pace method over measurement domain and position domain are as follows: 1) the state-space approach has superior spatial decorrelation properties so that performance is independent of reference station locations, 2) fewer reference sites are required, 3) minimal bandwidth is needed to transmit the data, and 4) performance degradation is insignificant for single reference site loss and

degrades gracefully for multiple reference site loss.

Implementations of the state-space approach include WAAS (FAA in the US), EGNOS (European Triparite Group), MSAS (Japanese Civil Aviation Bureau), and of course JPL's GDGPS, and NRCan's GPS*C.

RTK

An alternative to DGPS service is real-time kinematic or RTK. Double differenced phase ambiguities between a reference station and the user allow baseline accuracies better than a few centimeters. The problem of RTK is the need to have reference stations within ~10 kilometers of the user. Beyond these distances, decorrelation of troposphere and ionosphere error impedes the resolution algorithms. In contrast, DGPS reference stations can exceed several hundred kilometers. Network methods such as RTK Virtual Reference Stations replace physical reference stations with virtual grid points, and can provide 2-5 cm accuracies with baselines of ~30 kilometers. The real-time RTK users however are inconvenienced with a large bandwidth requirement (~600 bytes/sec) and a low latency real-time link.

Real-Time Corrections

Industry standard correction streams have been implemented for the various differential services, including RTK.

<u>RTCM-104</u>

Many GPS receivers are "RTCM-capable" meaning they accept DGPS correction messages through a real-time data communication link (e.g., VHF or UHF radio, cellular telephone, FM radio sub-carrier or satellite com link). The Radio Technical Commission for Maritime Services Special Committee 104 recommended standards for DGPS correction messages in November 1983. These were first published in November 1987. RTCM-104, version 2.0 was later issued in Jan. 1, 1990. Version 2.1 dated Jan 25, 1994 primarily supplemented version 2.0 with the inclusion of message types 18/19/20/21 for carrier phase solutions such as RTK. And version 2.2 is the latest and includes enhancements to include GLONASS DGPS corrections.

The data format has been modeled on the GPS navigation message with the word size, word format and parity algorithms being the same. (5 bits of every 30-bit word are parity bits.) In version 2.0, there are a possible 64 different message types of which 21 were defined. Version 2.2 defines 33 out of the possible 64.

Type 1 is the primary message type for DGPS users and contains pseudorange and range-rate corrections, issue of data ephemeris (IODE), and user differential range error (UDRE). Delta corrections due to a change in IODE are available in the Type 2 messages. Type 3 messages contain the ECEF location of the reference station with a one-centimeter lsb.

In Type 1 messages, 40 bits are reserved per PRN. Of these, 5 bits are for satellite id so that PRNs 1-32 is possible. (00000 represents sat id 32.) Sixteen bits are reserved for the pseudorange correction. The dynamic range of these pseudorange corrections (with SF = 0) is +/- 655.34 meters with an lsb of 2 centimeters. Additional resolution can be obtain with RTCM version 2.1 message Types 19 or 21. For RTK applications, RTCM version 2.1 provides Type 18 (carrier phase raw data) or Type 20 (carrier phase corrections).

RTCA-159

Radio Technology Committee for Aviation Special Committee 159 develops minimum standards that form the basis for FAA approval of equipment using GPS for aircraft navigation in the US. The RTCA DO-229 document entitled "Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment" was prepared by SC-159 in 1996. It contains the standards for airborne navigation equipment using GPS augmented by WAAS. EGNOS and MSAS users also follow this standard. The standard specifies how to integrate satellite orbit and clock, and ionospheric corrections with measured GPS data.

JPL correctors

The message format for JPL's GDGPS was designed to be low-bandwidth and yet contain sufficient resolution to allow the user to perform sub decimeter positioning. Unlike RCTM-104, the message contains no parity bits, and unlike RTCA-159 there is no PRN mask, and no ionosphere corrections. The GDGPS 44-byte correction messages are generated at 1Hz. A complete sequence of potentially 32 PRN messages is delivered to the user within 32 seconds. The sequence is then repeated. If a PRN doesn't exist or is listed as unhealthy, the corresponding message block is not transmitted. New clock corrections for all PRN's are generated at 1 Hz and each message block contains updated centimeter-level clock corrections for all PRN's. Table 1 presents more details of the message.

Table 1: 44-byte GDGPS correction message detail.

Field	Number of bits	Possible values	Numerical Range	LSB	Meaning
Message block #	5	2^5 (32)	0-31	1	Corresponds to PRN #
Time tag	11	2^11 (2048)	0-1799	1	GPS time modulo 30 minutes
IODE	8	2^8 (256)	0-255	1	Issue Of Data, Ephemeris
Orbit X, Y, Z	13	2^12-1 (+/- 4095)	+/- 31.9921875 meters	1/128 m (0.78125 cm)	Orbit correction to the ECEF X, Y, Z phase position of the broadcast ephemeris, at time tag
Orbit X, Y, Z dot	6	2^5-1 (+/- 31)	+/- 3.7841796875 meters	1/8192 m (0.1220703125 mm/sec)	Rate of change of the X, Y, Z orbit correction at time tag
Meter clock	8	2^7-1 (+/- 127)	+/- 127 meters	1 m	Meter-level clock correction
Cm clock (32 total)	8 each	2^7-1 (+/- 127)	+/- 99.21875 cm	1/128 m (0.78125 cm)	Cm-level clock correction

Recommendations

- UDP transport protocol preferred for real-time data and product distribution.
- Continue with real-time network prototype development.
- Encourage organizations operating real-time data networks to reformat a subset of their data into the format proposed by the RTWG and permit easy access to these real-time data streams.
- Recommend state-space approach for precision GPS service.
- Develop new or adopt existing differential GPS message format.

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References

Abousalem, M (1996), Development and Analysis of Wide Area Differential GPS Algorithms. Ph.D. Dissertation, Department of Geomatics Engineering, The University of Calgary, Calgary, Alberta, Canada, 20083.

Satloc Wide Area Differential GPS System, Gary Penno, Mike Whitehead, Walter Feller, *Satloc Inc.,* Proceedings of the Institute of Navigation, GPS-98, Nashville, TN.