# 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

## Geodetic Survey Division

## Natural Resources Canada

**Abstract**

This paper discusses several of the next steps in the development of a real-time infrastructure capable of supporting the continuous exchange of data and products. These next steps include expanding the network, adopting station and network management procedures, and the identification of useful products for the real-time end-user.

**Introduction**

At the April 2002 IGS workshop, a prototype architecture was agreed upon as a means of moving forward and implementing a mechanism for real-time data and product exchange within the IGS. To date considerable progress has been made. A prototype real-time network is now in place enabling real-time data distribution among a number of IGS agencies. We review the prototype architecture and then discuss potential products for the real-time end-user.

## Prototype Architecture for Data Distribution

We begin with a review of two fundamental elements of the prototype architecture, the transport protocol and the chosen data format.

**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. Natural Resources Canada's (NRCan), GeoForschungsZentrum's (GFZ) and the Jet Propulsion Laboratory's (JPL) GPS groups recognized early the advantages of UDP for data flow and have implemented data flow technologies that extensively use the UDP protocol.

The Real-Time Working Group (RTWG) has adopted a common data format and method that allows 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 four record types |
| 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 |
| 21 bytes per GPS observation in JPL soc format | | |

For a receiver tracking 10 GPS satellites, the number of bytes in a packet would then be 222 (12 + 21*10). NRCan's udpRelay additionally layers this with a 24-byte header and appends a 16-byte Message Authentication Code (MAC).

**Station Management**

The operation of a cooperative network requires procedures for managing changes to a station. From a procedural standpoint, the need to manage change is no different whether you are considering hourly files or real-time streamed data. Station operators must still notify users of a change and this must be done in a timely manner so that users of the data are not surprised by the change. It is also the station operator's responsibility to inform real-time users of these changes. This must be done prior to or coincident with the reintroduction of the station's data into the real-time stream.

It is proposed that this be accomplished in the following way. Observation packets contain an issue of data station (IODS) that can be traced back to information stored for example in a SINEX template for each station. Station configuration packets will be transmitted at regular intervals in the real-time data stream. This record will contain information that can be traced to changes in the station's configuration such as the station's height, coordinates, receiver type, antenna type, ray dome and eccentricities-NEU. Provided that the IODS in both the data observations and the station record match, users of the data can be assured that they are using the correct station information. Station operators must be diligent in managing the IODS information and real-time users must insure that data is used only when the IODS information agrees in both the observation and station record.

**Network Management**

A prototype network is currently being managed at Natural Resources Canada where statistics for average latencies and percentage of availability are computed for all of the stations in the network. Similar statistics are maintained for JPL's network. These statistics are invaluable to assess the performance of particular stations. It is particularly valuable to present these statistics in near-real time and in public view such as a web link. Additional information to present would be:

- Receiver based statistics (number of satellites being tracked)
- Station data integrity (a means to alert users of problems)
- IODS information (changes in IODS indicate station change)
- GPS observability (holes in the network)

One of the more important steps is to make available to the user community a global distribution of stations. The emphasis has been on providing data from agencies whose networks are global in scope. Soon this emphasis will be switching to one that concentrates on the addition of real-time stations from agencies who wish to make single station contributions. This will be critical in order to fill in the weakest portions of the network as well as to provide additional redundancy.

Opportunities exist for contributions to these next steps. Apart from contributing data, agencies are encouraged to contemplate contributions to real-time processes that will provide inputs to network management processes, including receiver-based statistics and station data integrity.

**Near Real-time Data Availability**

The availability of real-time connections will create new opportunities for the IGS. Timely data could immediately have a positive impact on the generation of ultra rapid products by reducing the latency of the data accessed by the analysis centers. File representations of the data streams should be made available to the IGS Data Centers for timely distribution.

## Towards Real-Time Products

The remainder of the paper is intended to stimulate discussion on topics consistent with Phase 2 of the RTWG's charter which include:

- Develop the real-time combination of orbit, clock and ionosphere products.
- Develop a real-time robustness and reliability/integrity monitoring methodology.

### 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 Tripartite 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. It should be determined what type of product can be produced that would best aid the real-time end-user.

<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).

<u>RTCA-159</u>

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 |

NRCan correctors

Natural Resources Canada has adopted the RTCA-159 format with extensions to increase the resolution of the corrections. Table 2 presents more details of the message.

**Table 2: GPS•C MRTCA Message Types**

| | Information | Type | Content | Resolution | Effective range | Max Update Interval (s) |
|---|---|---|---|---|---|---|
| Standard RTCA | Fast | 1 | PRN mask | N/A | N/A | 60 |
| | | 2-5 | Correction | 0.125m | ±256 m | 2 |
| | Mixed Fast/Slow | 24(0) | Correction<br>Orbit offset<br>Clock offset | 0.125m<br>0.125m<br>0.140m | ±256 m<br>±32 m<br>±71.48 m | 2 |
| | | 24(1) | Correction<br>Orbit offset<br>Clock offset<br>Orbit rate<br>Clock rate | 0.125m<br>0.125m<br>0.140m<br>0.488mm/s<br>0.545mm/s | ±256 m<br>±128 m<br>±142.95 m<br>±62.5 mm/s<br>±69.8 mm/s | |
| | Slow | 25(0) | Orbit offset<br>Clock offset | 0.125m<br>0.140m | ±32 m<br>±71.48 m | 120 |
| | | 25(1) | Orbit offset<br>Clock offset<br>Orbit rate<br>Clock rate | 0.125m<br>0.140m<br>0.488mm/s<br>0.545mm/s | ±128 m<br>±142.95 m<br>±62.5 mm/s<br>±69.8 mm/s | |
| | Ionospheric Grid | 18 | Grid mask | N/A | N/A | 300 |
| | | 26 | Vert. delay | 0.125m | [ 0, 63.875 ]m | 300 |
| | Time | 12 | GPS week<br>GPS sec of week | 1 week<br>1 sec | [ 0, 1023 ] week<br>[ 0, 604799 ] sec | 300 |
| Non-Standard | Nav Msg | 28 | 1 subframe | N/A | N/A | 7200 |
| | Fast (High-res) | 32-35 | Correction | 0.0039m | ±64 m | 2 |
| | Slow (High-res) | 45 | Orbit offset<br>Clock offset<br>Orbit rate | 0.0039m<br>0.0039m<br>0.006mm/s | ±32 m<br>±71.5 m<br>±7.8 mm/s | 120 |

NICE

The New and Improved Clock and Ephemeris (NICE) message is proposed for the modernized signals. These messages will improve the curve fit error by adding new parameters for semi-major axis rate, delta mean motion rate, and increasing the resolution of other parameters. Additional accuracy information in the form of URA bits is also included.

State Vector Representation

DiEsposti et al [2004] has proposed new state vector and covariance matrix representations for the broadcast on the modernized GPS signals. To obtain the GPS ephemeris, user equipment would numerically integrate the force models. Realistic LOS range and rate errors would also be obtained by propagating the covariance. This representation eliminates fit errors and permits for long duration ephemeris propagation.

## Recommendations

- The UDP transport protocol is preferred for real-time data and product distribution.
- Organizations operating real-time data networks are encouraged to reformat a subset of their data into the format proposed by the RTWG and permit easy access to these real-time data streams. RTWG will provide information to make the mechanism for access clear.
- Together with the DCWG, the RTWG will assess long-term archival and provision of the data in the RT streams.
- The RTWG and DCWG will together map a strategy to provide assessments of the RT data streams.
- Quality monitoring of the predicted portion of the IGS Ultra Rapid orbits is an initial RT product goal (joint with Integrity Monitoring session).
- More frequent, exploratory communication among RTWG members is needed.

### Acknowledgement

The work described in this paper was carried out in part by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

### 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.

DiEsposti, Raymond, *et al.*, The Proposed State Vector Representation of Broadcast Navigation Message for User Equipment Implementation of GPS Satellite Ephemeris Propagation, Proceedings of the Institute of Navigation, January 2004, San Diego, CA.