The Canada-Wide Differential GPS (CDGPS) Service: New Infrastructure Launched for GPS-based Geo-Referencing and Navigation

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Biography
Amin M. Kassam is a professional engineer and Land Surveyor with over 20 years experience in the geomatics field and manages the geo-spatial reference program for British Columbia. Amin, *Brad Hlasny* and *Vern Vogt* have established British Columbia's reputation as a leader in Canada in the establishment of real-time DGPS infrastructure and services.
Kim Lochhead represents the world-renowned GPS and wide-area networks team of experts at Geodetic Survey Division.
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Abstract
The new Canada-wide differential GPS (CDGPS) service will be launched by the end of 2002. This is an important development for spatial data gatherers in Canada (and in fact North America). Under development over the past few years, this **free** service will enhance the availability of real-time DGPS corrections across Canada. All provinces, the government of Nunavut and the Federal government have partnered to bring quality geo-referencing capability for GPS users within the Canadian Spatial Reference System (CSRS). CDGPS will augment the Coast Guard's marine beacon DGPS service as well as the United States' Wide Area Augmentation Service (WAAS) by providing complete Canadian coverage and simple access to the CSRS.

Governments have recognized the need for and the utility of DGPS serving the land and resource sectors. As such, efforts have been underway in both the United States and Canada to cost-effectively build the necessary infrastructure to support *real-time* DGPS. CDGPS is the Canadian response.

CDGPS is based on the Canadian government's Canadian Active Control System (CACS) and its wide-area based real-time GPS correction (GPS•C) product. As its first release under CDGPS in 2002, GPS•C is being delivered to the users through the MSAT-1 communications satellite operated by Mobile Satellite Ventures (MSV). Mobile Knowledge Inc. (formerly SiGEM Inc.) of Kanata, Canada is the prime contractor who developed and built the satellite network components, including the open broadcast protocol, the hub, and the radio (user receiver). MSV was sub-contracted for some of the hub development and will be responsible for the network operation. As an initial seed to the marketplace, a user receiver has been built and will be offered to the marketplace to help launch the CDGPS service. The user receiver is designed to be highly portable and permit three output options:

- CSRS position (i.e. corrected position) in NMEA format,
- Local differential RTCM-104 correction stream, and
- GPS·C in modified RTCA (MRTCA) format.

Introduction
The new Canada-wide differential GPS (CDGPS) service will be launched at the end of 2002. This is an important development for spatial data gatherers in North America. Under development over the past few years, this **free** service will enhance the availability of real-time DGPS corrections across Canada. All provinces, the government of Nunavut and the Federal government have partnered to bring quality geo-referencing capability for GPS users located within the Canadian Spatial Reference System (CSRS). CDGPS will augment the Coast Guard's marine beacon DGPS service as well as the United States' Wide

Area Augmentation Service (WAAS) by providing complete Canadian coverage and simple access to the CSRS. Governments have recognised the need for, and the utility of, DGPS serving the land and resource sectors. As such, efforts have been underway in both the United States and Canada to cost-effectively build the necessary infrastructure to support *real-time* DGPS. CDGPS is the Canadian response.

The corrections are based on NRCan's wide area network called the Canadian Active Control System (CACS) and are computed at two independent and redundant sites. The service makes use of a Geo-stationary satellite, MSAT-1 (and backed up MSAT-2), to deliver the corrections to the end users. The initial offering of the service will be received by custom, purpose-built satellite receivers. However it is expected that other manufacturers and service providers will step in and develop other platforms for their particular applications.

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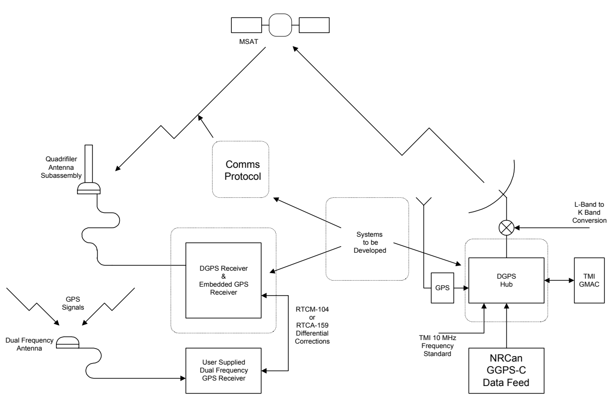

Figure 1. CDGPS Network Diagram

Governance
A Management Board comprising three Canadian federal-provincial representatives, a member from academia (Dr. Richard Langley, University of New Brunswick) and an industry member (Dwight Howse, Canadian Centre for Marine Communications) governs the CDGPS program. The British Columbia government, on behalf of the consortium runs the Project Office. Geodetic Survey Division of Geomatics Canada provides provisioning of the wide-area, CACS-based GPSC corrections, as input into the CDGPS service requirements, design and delivery. Advisory support and co-ordination among federal-provincial agencies is through the Canadian Geodetic Reference System Committee (CGRSC), a sub-committee of the Canadian Council on Geomatics (CCOG). CCOG is the driving force behind the inception of CDGPS and its member agencies also represent the funding partners for the program.

Service Objectives
The service is designed to operate as public infrastructure and as such GPS and other vendors will be encouraged to take in the GPS•C (MRTCA) stream, as well as develop other DGPS and DGPS-based services. To that end an initial launch of the service will place a significant number of radios into Government department and industry clients to allow them to gain an appreciation for the benefits of the service. It is hoped that the availability of no cost real time differential corrections anywhere in Canada will be the genesis of a new era in GPS based spatial positioning using the CSRS. For further information see *http://www.geod.nrcan.gc.ca/index_e/index_e.html.*

DGPS is an important tool for reliable and accurate 1–5 m positioning using GPS. In particular, and despite the removal of SA, many GPS users do not appreciate the need for DGPS. Most users do not operate in open and ideal conditions for GPS. As such, the effects of multipath, ionosphere and poor geometry, as well as general reliability concerns, are not properly taken into account. CDGPS has evolved from the Local DGPS technology and service as developed through the Global Surveyor^{TM} program in British Columbia (http://home.gdbc.gov.bc.ca/bcacs/glblsrvy/gs_prov.htm) Based on that experience, including the associated work on GPS standards for land based applications, the CDGPS service has been designed to provide a simple yet robust answer to some of these problems. The CDGPS applications are expected to be broad and include:

- Aerial Mapping: e.g. navigating and resource mapping from a helicopter
- Airborne Guidance: e.g. guiding the application of fertilizer/ herbicide
- Bathymetric Surveying: e.g. dynamic positioning of survey launches on lake and fjords

- Engineering: e.g. creating a plan view of a golf course to design a drainage system and locations for fairway reconstruction
- Environmental: e.g. mapping occurrences of Douglas Fir Tussock Moth and Gypsy Moth
- Forest Inventory and Silviculture: e.g. relocating start and end points of line transect plots which had been spaced and pruned since previous mapping was completed
- Forestry Pre and Post Harvest Mapping: .e.g. maintaining maps locating pre harvest boundaries and mapping post harvest blocks
- Fisheries Inventory: e.g. mapping streams and creeks
- GIS Data Capture and Mapping
- Precision Agriculture: e.g. regulating the quantity and location of the application of fertilizer and herbicides or pesticides
- Surveying: e.g. locating lot corners to identify forest license boundaries, or georeferencing remote parcels for inclusion in reference maps
- Road Inventory Mapping: e.g. mapping main haul roads
- Wildlife: e.g. sampling wildlife habitat sites

Figure 2. Regulated Pest Spraying (Gypsy Moth)
(Courtesy of BC Government Website)

CDGPS is not intended to meet public safety applications that require very high availability and reliability. As described above the applications cover varied areas but not "life and limb" requirements. The target availability for CDGPS is 99.8% over any one-month period.

System Design and Supporting Infrastructure

As already described the CDGPS service is designed to provide a mechanism for users to receive the CACS wide area corrections anywhere in North America. Currently the data in the corrections only supports Canada and the northern United States. However, there is nothing in the system that would preclude the expansion of the coverage if the CACS feed were to be expanded.

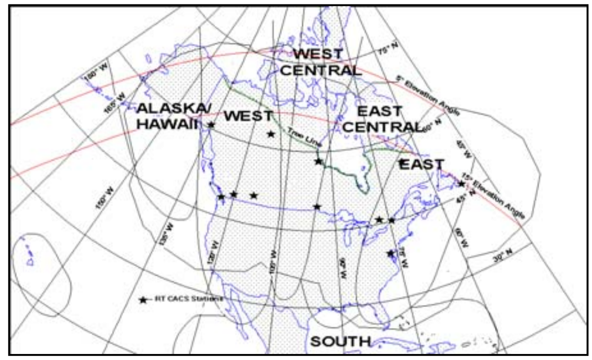

Figure 3. CDGPS Coverage Map

The system design revolves around a few key elements. The delivery mechanism, the source data, and the receivers.

Delivery Mechanism

The delivery mechanism was chosen to be the MSAT satellite that has several excellent characteristics that are beneficial to the service. It is a high power L-Band mobile communications satellite placed in a Geo-stationary slot over North America. It provides ubiquitous coverage of the continent and the entire coverage area of the CACS infrastructure. The L-Band spectrum is co-polar with the GPS downlink signal and very close in frequency to the GPS carrier. This allows the use of common antennas and receiver front ends for any shared GPS/CDGPS receivers to be developed. There are three main components that make up the complete MSAT portion of the CDGPS system, the satellite hub, the satellite, and the RF protocol that transports the data.

The Satellite hub is the interface between the source data and the MSAT satellite and ultimately the user's receiver. The hub accepts both the source data feeds and queues the individual messages for transmission. Priorities are assigned based on message type and GPS network stability with the highest priority given to messages that contain information regarding a recent change in the network status and subsequent priorities assigned based on the latency requirements of the messages. Once queued the messages are then shifted through the protocol algorithm. The hub also provides for an extensive self-monitoring of all messages transmitted over the network. Each message leaving the hub is demodulated and compared with the message transmitted to ensure no errors have been introduced into the data. At the end of the chain of hub monitoring are the human operators that are on duty 24/7 and are apprised of any failures through their monitor and control interface.

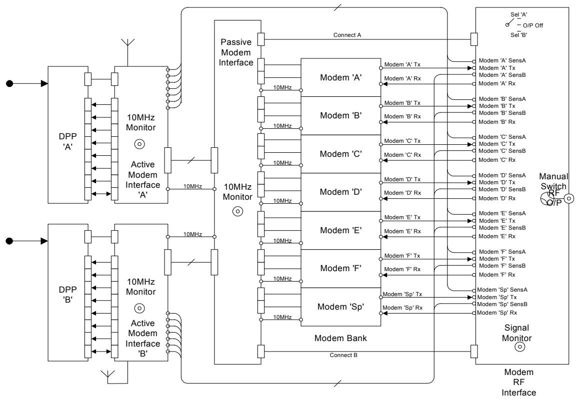

Figure 4. CDGPS Hub Design

Key RF Protocol Design

A key element of the service and its excellent performance in difficult receiving situations is the RF protocol. The protocol has been designed to maximise the probability of correct message reception while controlling the latency of the messages to an acceptable level. Another key requirement was the time to first fix (TTFF) based on receiving a full complement of the current MRTCA messages. Also of importance is the inclusion of an embedded signalling channel within the message stream that can be used by receiver designers to put the receiver in a sleep mode when they have received all the current data and wake up when new data is available. This will allow for DC power saving features to be designed into those products operating on limited power storage.

To achieve all these features the protocol performs the following operations on the incoming data stream. Initially the messages are divided into two groups: those with tight latency requirements and those with relaxed latency requirements. The orbital clock corrections are the primary messages in the first group called the "FAST Messages" group. Once broken into the groups the messages then under go a number of operations to enhance the probability of reception. The messages are first Block encoded with a rate ½ Reed-Solomon code. Next these messages are interleaved to allow increased protection in a burst error environment. The FAST messages are 3-way interleaved while the SLOW messages are 13 way interleaved. After interleaving the messages are bit-scrambled to smooth the Power Spectrum of the transmitted signal. And finally the messages are convolutionally encoded at rate ½. Along the way two levels of frame and message synchronisation and a Walsh encoded signalling channel are merged into the transmitted bit stream. Once encoded the messages are then BPSK modulated on the RF carrier and uplinked to the satellite.

The readers are referred to a more detailed description of the protocol on the CDGPS website (www.cdgps.com).

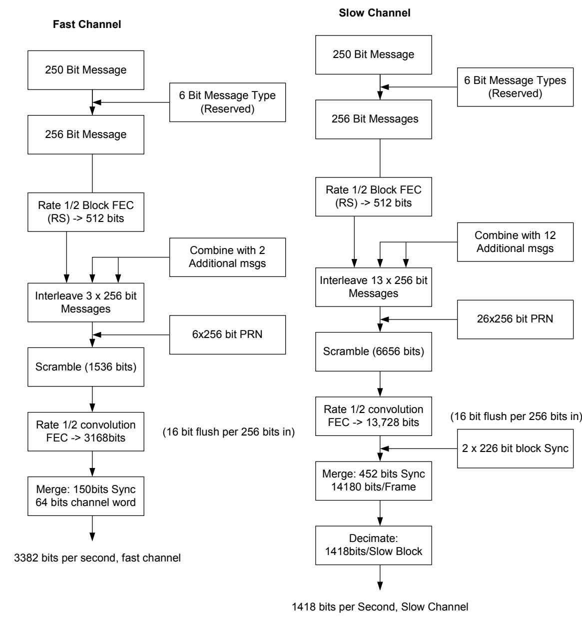

Figure 5. CDGPS Over the Air Protocol Schematic

For the purposes of this service the satellite merely transponds the uplinked signal and returns it to earth simultaneously on all of the four beams that make up the coverage area of the service. In each beam the CDGPS is assigned a unique frequency that users must tune.

Source Data

The source data is derived from the CACS network of Active Control Points deployed across Canada. These data are collected at two completely independent sites in Ottawa, Ontario, Canada where the final corrections and messages that comprise the CDGPS feed are created. The CACS continuously record carrier phase and pseudo-range measurements for all satellites of the Global Positioning System (GPS) within station view. Each ACP is equipped with a high precision dual frequency GPS receiver and an atomic frequency standard. Temperature, pressure and humidity data are also collected at selected ACP sites. These two independently derived sets of data are transmitted to the satellite uplink hub located at MSV in Ottawa via high reliability Frame Relay connections.

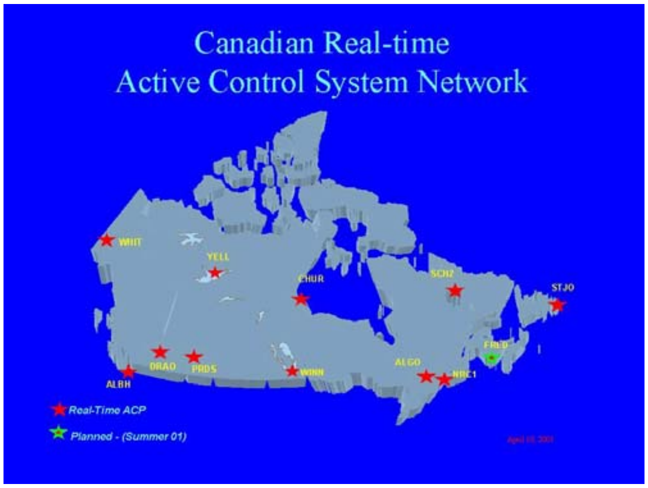

Figure 6. Canadian Active Control Systems (CACS) Network

Receivers

The service has been defined with the goal of stimulating use and interest in the differential corrections produced by NRCan and as supported by the CDGPS partners. It is expected that through the availability of the open protocol and other development tools that industry and academia will find it a relatively simple matter to access the satellite feed for their particular application. Having said that, and to start somewhere, the first generation receiver has been developed by Mobile Knowledge Inc. in Kanata, Ontario, Canada. This hand held field portable unit has an onboard GPS receiver and a DSP based receiver for extreme sensitivity to low signal levels that will be encountered in normal usage. The receivers weigh approximately 500 grams and come with a standard patch antenna or an optional higher gain quadrafilar antenna for higher latitude/demanding condition users. They are designed to work on either 4 AA batteries or through an external 12 VDC power source. The unit is ruggedized and splash proof.

Figure 7. CDGPS Receiver

The receivers have a simple user interface that allows the selection of the MSAT downlink beam frequency and the format of the data to be output. The user will select between one of the following three choices of data:

- CSRS position (corrections applied) in the NMEA format. Users may attach a Personal Digital Assistant (PDA) or other device to receive corrected CSRS positions at an expected 5 m (95% confidence) level.
- An RTCM-104 correction stream based on the CDGPS receiver position (i.e. wide-area corrections that have been "localized" to the users location). Users may select the RTCM option and pass on pseudo-range corrections to any “DGPS-ready” or “RTCM-ready” GPS receiver in order to achieve an expected 1-5 m positioning (95% confidence)
- GPS•C in modified RTCA (MRTCA) format. This allows the CDGPS receiver to be interfaced to a dual frequency GPS receiver capable of receiving the MRTCA format, thereby achieving up to few decimetres (95% confidence) positioning. Until dual frequency GPS receivers interface directly to this output, these highest accuracy results are possible through the use of an intermediate processing system such as a PC interfaced to a dual frequency GPS receiver.

Quality Control and Quality Assurance

There are three main aspects to the quality of the CDGPS service: i) the accuracy, completeness and consistency of the data being delivered, ii) the reliability of the delivery channels and iii) the ability of the receiver to reliably decode the messages.

The accuracy, completeness and consistency of the data is ensured by the heritage of the CACS system. This service has been under development for many years and has grown into an operationally robust service with a significant track record. To support the CDGPS service, the CACS has been expanded to include more Active Control Points, a managed service environment that includes a separate development environment, and two dedicated and independent servers to calculate and supply the data. The use of the separate development environment and dual server approach allows for ongoing enhancements and upgrades without disrupting the service data. As part of the heritage of this system is the inclusion of an integrity monitoring service on each server.

The data delivery system reliability has been assured by the use of redundant communication channels in all cases. With the exception of the satellite itself there are no communication channels in the service that are not completely redundant. MSAT-2 provides a manual back-up in the event of satellite failure. It is interesting to note that under the Global Surveyor service in British Columbia, MSAT-1 availability has been better than 99.9% on an annual basis

The goal of the service is to make the data available to all free of charge and to encourage as many participants in the development of services based on the CDGPS as the market will bear. As in the standard GPS market, it will be up to the developers of the end services and products to ensure the quality of their placements. Having said that, as part of the roll-out of the service an initial receiver design is included to allow people to use the service from the start without any further development. The quality of these initial devices has been a key requirement for the developers and the units will be supported with a 1 year manufacturer's warranty.

Users' Access and Distribution Channels

A distribution network for the CDGPS receivers is being set up in Canada. Through a solicitation, a number of companies have been screened and it is expected that several will market and distribute the receivers in several vertical markets. The distributors will be at the front lines of CDGPS and will provide the necessary sales and support. It is expected that the CDGPS receivers will retail for less than $1500 Canadian (i.e. less than $1000 US). The government partner agencies forming the CDGPS consortium will promote the service within the government markets and seed those applications with CDGPS receivers. The CDGPS project office will provide the necessary back-up and support for the distributors and any emerging players wishing to take advantage of the open broadcast protocol, i.e. to build or integrate their own CDGPS receiver. *CDGPS.COM* is the main web site for information about CDGPS and contact points. The site will also offer visibility into CDGPS performance through various means, including reporting of any system outages and a "remote monitoring system".

Remote Monitoring System

A remote monitoring system (RMS) is being implemented to assist CDGPS monitoring and provide public views to CDGPS availability, reliability and accuracy. The RMS sites across the country each receive the CDGPS receiver-based corrected positions at those sites and provide various on-line, Internet Web-based, views of the data. Apart from the Project Office site at Victoria, British Columbia, several other sites are currently being implemented, including those at the University of New Brunswick (UNB) and the University of Calgary. A test bed is already in operation and it is expected that several sites will be operational before service launch later this year.

The figure below is an example of a scatter plot from the RMS, in this case showing 2D positions over approximately 20 minutes. Statistics from this noisy site show mean 2D errors over an hour of as good as 2.5m – 5m (95% confidence) or better.

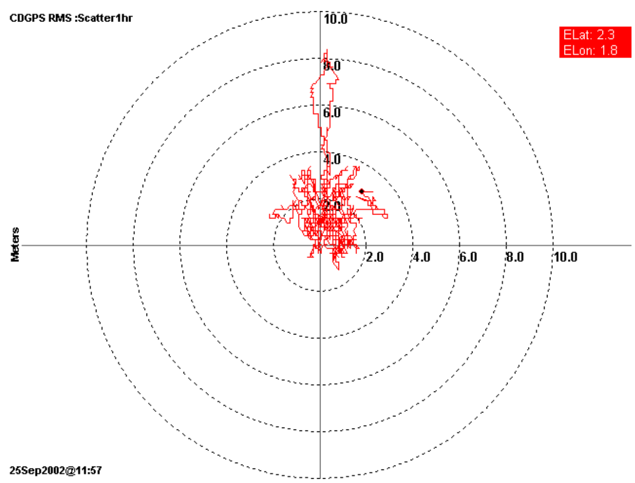

Figure 8. CDGPS-RMS 1 hour Scatter Plot/View

The figure below depicts a trend plot from the RMS, showing errors in latitude, longitude and height, and HDOP, number of satellites being tracked. This trend plot and previous scatter plot are examples of the views that any user will be able to see from the RMS sites on a 7/24 basis. Users will also have real-time access to these, as well as be able to retrieve archived plots and statistics.

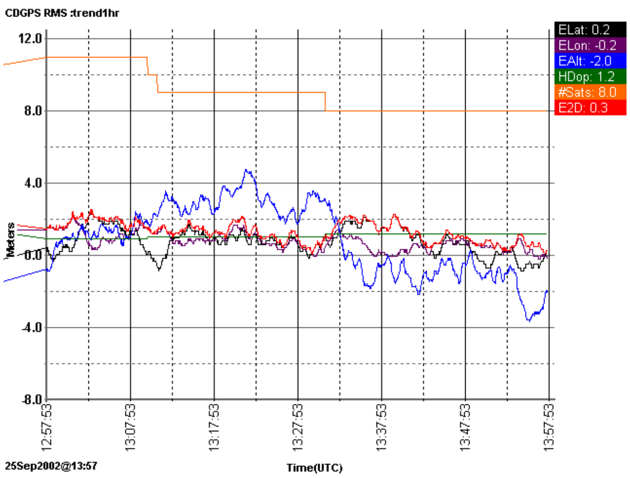

Figure 9. CDGPS-RMS Error vs. Time 1 hour Plot/View

Note that the above plots are currently monitoring the pre-Alpha CDGPS Service at a noisy site and utilise the CDGPS receiver's internal chipset (consumer grade GPS receiver). As such, errors and anomalies are much larger than would be expected with the final service offering.

Service Testing, Results and Adoption

As of September 2002, the CDGPS service development is nearing completion and field trials (Alpha testing) have already begun. Preliminary results are very encouraging and it is expected that the full system objectives will have been met prior to service launch, which is likely to occur in December 2002. Over fifty (50) Beta Trials participants from across Canada are ready to try out the system in November and validate system performance before system launch. These users are from various sectors and will utilize the service in various conditions, including on foot, in moving vehicles, in open conditions, under forest canopy, and with many different interfaces: PDAs, consumer-grade DGPS receivers, mapping-grade DGPS receivers and higher end DGPS receivers. The results of the noted Alpha and the Beta Trials will be published on the CDGPS web site (www.cdgps.com).

Service adoption activities within the market place will continue through the CDGPS distributors and through the Project Office as the system is launched and beyond.

Pre-Alpha Test Results.

Pre-Alpha testing has been underway in the Victoria, British Columbia area since late August. Tests concluded include comparison of under canopy performance with another MSAT based DGPS solution (the Global Surveyor™ Service), accuracy assessments and comparison with other solutions such as the Global Surveyor™ Service and Canadian Coast Guard Beacon, and dynamic, vehicle mounted tests.

Coverage Under Canopy

The preliminary performance indications of the service appear to be very good under difficult field conditions. In this case, performance is defined as the percentage of the corrections that are acquired at the receiver under varying field conditions. The figure below indicates performance achieved at the Francis King Park test range. Note that MSAT is to the SE in this plot, at an azimuth of approximately 167 degrees.

This data was logged using the internal GPS chipset to output to NMEA format. In this particular dataset, 84% of the GPS fixes observed were corrected. Much of this traverse is in very difficult GPS conditions, with much of the eastern portion running through large Douglas Fir with diameters of 1m or more. In the southern portion of the traverse, the line of sight to MSAT travels through dense Maple and Oak foliage. However, the poor GPS conditions are indicated by the separation of the forward and reverse traverse along the southern portion. All accuracy testing has been undertaken using the internal GPS chipset and external GPS receivers.

Single frequency DGPS Accuracy

Evaluation of the achievable accuracy of the system for single frequency users has been undertaken at local geodetic control monuments in the vicinity of Victoria. Simultaneous testing has been completed with BMGS' Trimble ProXR and the internal GPS chipset. Preliminary results from a limited number of samples are shown in the following table. Further testing and refinement of the service are underway.

Table 1. CDGPS Accuracy – Integrated GPS Chip and Trimble ProXR (misclosure in metres)

Receiver	Avg. e2D	Avg. eH	Avg. e3D	Max e2D	Max e3D
Internal Chipset	4.46	-1.59	5.19	7.54	8.59
ProXR	1.20	0.97	1.92	3.09	10.82

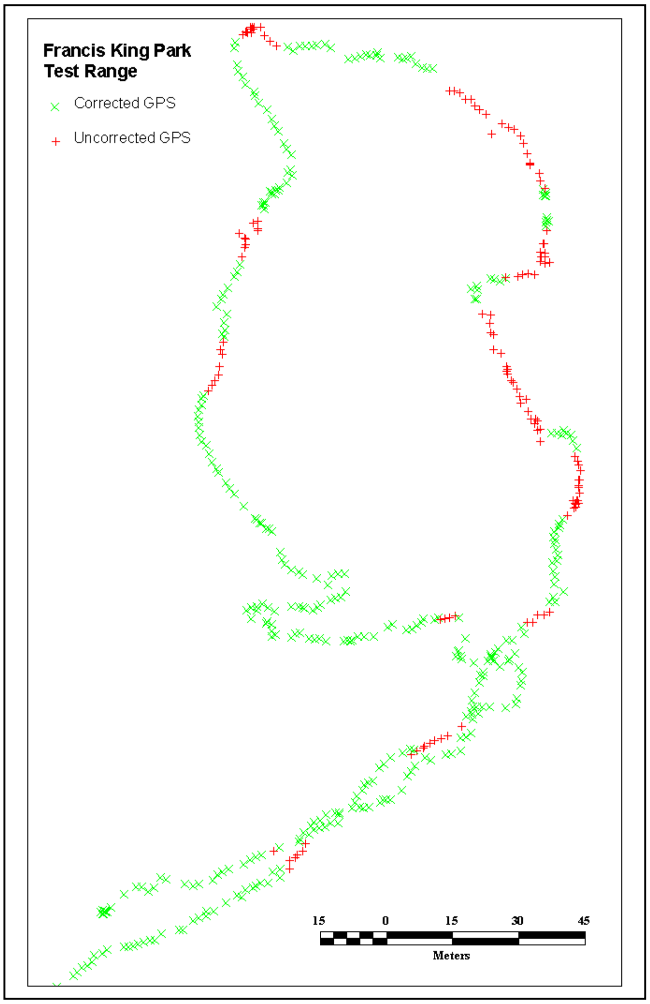

Figure 10. CDGPS reception in traverse under heavy forest canopy

Concluding Remarks

CDGPS testing and service finalization is in the final stages. Testing of the service for the dual-frequency capability, using the MRTCA feed, have yet to be field-tested. However, it is expected that up to few decimetre (95% confidence) positioning will be demonstrated. As well, improvements in the GPSC data, emanating from CACS improvements over time, will improve CDGPS user positioning.

As with any development program, the service development has taken longer than expected and provided many challenges; however, the development teams at Mobile Knowledge, Base Mapping and Geomatic Services Branch, and at Geodetic Survey Division have managed to stay focused on the service objectives in overcoming all technical and administrative difficulties. The emerging CDGPS infrastructure is therefore expected to be robust. It will meet user expectations, it will be flexible to accommodate continuous improvements in positioning accuracy as well as provide open access to those wishing to take advantage of the free signal, and it is extensible to provide full North American coverage as well as adaptation to other regions around the world.

References

1. ***GPS•C Real Time Correction Service of the Canadian Active Control System***. Geodetic Survey Division of the NRCan, revised 1997.
2. ***The Global Surveyor Real-Time Correction Service.*** Presented at GIS 1999
3. ***Canada-wide Differential GPS (CDGPS) Service Interface Control Document - NRCan to TMI Messages.*** (Doc#CDGPS ICD: NRCan to TMI).
4. ***Canada-wide DGPS Service Broadcast Protocol***. March 8, 2002 (preliminary release).