A Distributed System for the Dissemination of DGPS Data through the Internet

Manuel G. Soares, Benedita Malheiro and Francisco J. Restivo

Abstract — **In this paper we describe a low cost distributed system intended to increase the positioning accuracy of outdoor navigation systems based on the Global Positioning System (GPS).**

Since the accuracy of absolute GPS positioning is insufficient for many outdoor navigation tasks, another GPS based methodology – the Differential GPS (DGPS) – was developed in the nineties. The differential or relative positioning approach is based on the calculation and dissemination of the range errors of the received GPS satellites. GPS/DGPS receivers correlate the broadcasted GPS data with the DGPS corrections, granting users increased accuracy. DGPS data can be disseminated using terrestrial radio beacons, satellites and, more recently, the Internet.

Our goal is to provide mobile platforms within our *campus* with DGPS data for precise outdoor navigation. To achieve this objective, we designed and implemented a three-tier client/server distributed system that, first, establishes Internet links with remote DGPS sources and, then, performs *campus*-wide dissemination of the obtained data. The Internet links are established between data servers connected to remote DGPS sources and the client, which is the data input module of the *campus*-wide DGPS data provider. The *campus* DGPS data provider allows the establishment of both Intranet and wireless links within the *campus*. This distributed system is expected to provide adequate support for accurate outdoor navigation tasks.

Index Terms—**Differential GPS, Internet, Distributed Systems.**

I. Introduction

The work presented in this paper is part of a larger framework where mobile platforms equipped with GPS/DGPS receivers are expected to perform precise outdoor navigation tasks.

The need to improve the accuracy of the position readings we were obtaining with standard receivers in the outdoor navigation tasks carried at our *campus* led to the research and development described in this paper.

A way of improving the accuracy of GPS measurements is the joint use of Global Positioning System data and Differential Global Positioning System (DGPS) data. Appropriate receivers are then able to correlate data from both sources (the GPS satellite data and the DGPS correction data), granting users higher accuracy readings.

However, while the availability of continuous, worldwide GPS data (three-dimensional position, velocity and time data) to end users is guaranteed by the Global Positioning System (GPS), the same is not true with appropriate DGPS data sources.

The availability and adequacy of DGPS data sources depends, not only, on the nearby existence of DGPS base stations – the validity of the corrections depends on the distance between base station and rover, but also, on appropriate data dissemination over the area under consideration – when in differential mode, a GPS/DGPS rover expects to receive DGPS messages at a regular rate.

The specific corrections can be transmitted over various communication channels, e.g. via radio transmission (LF, MF, HF, UHF), a mobile communication network using different communication protocols or the Internet.

As a result, appropriate DGPS coverage raises the issue of reliable real time dissemination of the DGPS data within a target geographical area.

A. Problem

The problem we address in this paper is concerned with how to provide end clients located in our *campus* with real time DGPS data. This problem can be divided into three components: accessing appropriate DGPS sources, transporting the DGPS data to our *campus* and disseminating the data within the *campus*. The application described in this paper implements a data transportation system – through the establishment of Internet data links between DGPS base stations located in the vicinity of the *campus* and the *campus* premises – and a data dissemination system – through the implementation of a *campus*-wide DGPS data provider.

Data transportation is provided by means of a distributed (client/server) application whose role is to receive the DGPS data from the base station and to forward it all clients connected. The server-side application runs on a host machine connected to the DGPS base station. The client-side application runs on a host located at the *campus* and acts as the data input module of the *campus*-wide DGPS data

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provider.

Whenever new DGPS data arrives, the *campus*-wide DGPS data provider first verifies if all data requirements are met (age, error-free, etc.) and then disseminates the DGPS data within the *campus*. The overall service is expected to provide support for accurate outdoor navigation in our *campus*.

B. Paper Structure

This paper describes in detail this project. Section 1 introduces the reader to our motivation, problem and goal. Section 2 provides a brief description of the features of the GPS and DGPS systems. Section 3 presents the developed application and section 4 describes the current status of the project. Section 5 reports on related work and section 6 presents the conclusions.

II. Real Time Positioning

Nowadays, real time positioning is an activity supported by satellite-based systems, namely, the North-American NAVSTAR Global Positioning System (GPS) and the Russian Global Navigation Satellite System (GLONASS). In the near future, the European GALILEO satellite radio navigation system is expected to become the first non-military real time positioning system.

Since we are using standard NAVSTAR GPS receivers, we will briefly describe the NAVSTAR GPS and DGPS systems.

A. Absolute Positioning

The NAVSTAR Global Positioning System (GPS) is a real-time, all-weather, 24-hour, worldwide, 3-dimensional absolute satellite-based positioning system developed by the U.S. Department of Defence. This system consists of two positioning services: the Precise Positioning Service (PPS) and the Standard Positioning Service (SPS). PPS was developed for the U.S. military and other authorized users, uses the P(Y)-code on the L1 and L2 carriers, and provides an accuracy of 5 m to 10 m in absolute positioning mode. SPS is available to civilian users, uses the C/A-code on the L1 carrier, and provides accuracy of 10 m to 20 m in absolute positioning mode [7].

GPS utilises the concept of time-of-arrival (TOA) ranging to determine the user position. This concept entails measuring the time a signal transmitted by an emitter at a known location takes to reach a user receiver. This time interval, referred to as the signal propagation time, is then multiplied by the speed of the signal (the speed of light) to obtain the emitter-to-receiver distance. By measuring the propagation time of signals broadcasted from multiple emitters at known locations (the GPS satellites), the receiver can determine its position.

There are basically two general modes of determining the distance, or range, between a GPS satellite and a ground-based receiver antenna. These measurements are made by signal phase comparison techniques. Either the satellite's carrier frequency phase or the phase of a digital code modulated on the carrier phase may be used, or tracked, to resolve the distance between the satellite and the receiver. The resultant positional accuracy is dependent on the tracking method used. These two-phase tracking techniques are: carrier phase tracking and code phase (pseudorange) tracking.

B. Differential Positioning

The permanent quest for higher position readings accuracy led to the development of a GPS subsystem called the Differential Global Positioning System (DGPS). By definition, the DGPS method uses well-known geographic locations as references to detect the range errors of the GPS satellites. The method relies on a set of stations, called DGPS base stations, equipped with elaborated GPS receivers (12 channel single or dual receivers) and situated at precisely geo-referenced locations, to compute and broadcast the range errors of the GPS satellites received. The RTCM SC-104 protocol [12] is the DGPS broadcast protocol.

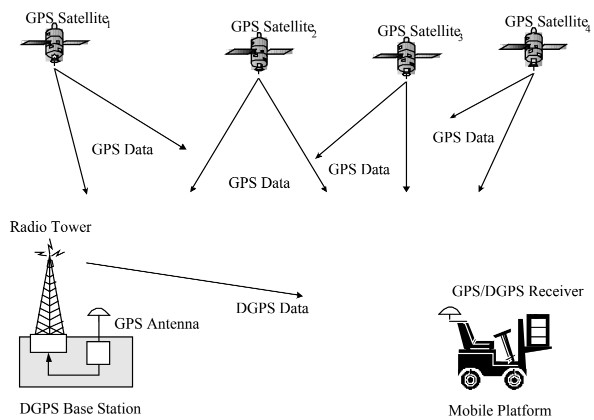

Figure II.1 – GPS/DGPS Positioning System.

With base stations and rovers recording observations at the same time, GPS processing software increases the accuracy of the position readings because it successfully eliminates the errors introduced by different sources of uncertainty (such as the variable delays introduced in the GPS signal when it crosses the ionosphere and the troposphere) and by the ephemeris and clock errors of the GPS satellites.

There are two real time differential positioning methods: code phase and carrier phase. DGPS utilizing code phase measurements – pseudorange corrections – can provide a relative accuracy of a few meters (1 m to 3 m). DGPS utilizing carrier phase measurements – real time kinematic (RTK) corrections – can provide a relative accuracy of a few centimetres.

DGPS pseudorange correction messages hold the pseudorange correction (PRC) for each satellite in view of the base station and the rate of change of the pseudorange corrections (RRC) calculated by the base station at the instant t_0. As a result, a mobile rover that receives such a message at instant t, is capable of calculating the pseudorange corrections that apply to the pseudorange measurements of each satellite in view: $\mathrm{PRC}(t) = \mathrm{PRC}(t_o) + \mathrm{RRC}(t - t_0)$.

Differential positioning using carrier phase tracking uses a similar formulation of pseudoranges used in code phase tracking systems described above. The process becomes somewhat more complex when the carrier signals are tracked. In carrier phase tracking, the short wavelength, 19 cm, necessitates adding an ambiguity factor to the solution equations to account for the unknown number of whole carrier cycles over the pseudorange. Methods for resolving the carrier phase ambiguity in a dynamic, real time mode have been developed and implemented by several GPS receiver manufacturers for real time positioning and are readily available today. [7].

Real Time DGPS can be implemented through terrestrial radio beacons, satellite constellations and, more recently, via mobile or Internet communications. While in the case of the coverage networks supported by radio beacons, the DGPS stations broadcast directly the corrections to the end-users receivers, in the case of the satellite supported networks, the base stations send the correction data to satellites which will broadcast the received data to the end-users equipment. In the case of the use of the Internet, data links between the DGPS base stations and the users have to be implemented using adequate technologies.

The receiver equipment and the access rules applied to the different types of DGPS data networks vary. While the DGPS data transmitted via radio beacon is public, free and complies with standard commercial GPS/DGPS receivers, DGPS data broadcasted via satellite is proprietary, requires the payment of an annual fee and the use of specific receiver equipment. The access to Internet links depends on the policy adopted by the service provider.

C. *RTCM SC-104 Protocol*

The Radio Technical Commission Special Committee N. 104 developed the standards for the differential global navigation satellite systems (GNSS) service. The RTCM SC-104 document defines the data messages and format, as well as, the features of the user interface [12]. Since it is the standard protocol for the dissemination of differential data, we will now describe the main features of the RTCM messages.

RTCM messages are composed of RTCM words, which, in turn, are made of five RTCM bytes. Since a RTCM byte is a 6-bit byte, a RTCM word is 30-bit long and accommodates 24 bits of data and 6 bits of parity.

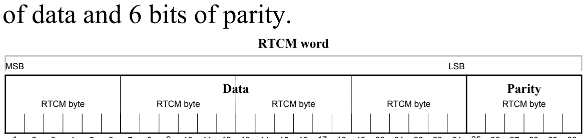

Figure III.5 – RTCM Word.

The parity information is used not only to guarantee the integrity of the data transmitted but, also, to encode the 24 bits of data of the following RTCM word, i.e., the data in a RTCM word is encoded according to the values of the two last parity bits (bit 29 and bit 30) of the previous word. The algorithm used to compute/verify the parity and to decode/encode the data bits of each RTCM word is the one specified for the GPS signal messages [6]. The parity algorithm links the 30-bit words within and across sub-frames of 10 words, using the (32, 26) Hamming Code.

Each RTCM message includes a mandatory header of two words, followed by a body of data of variable word length.

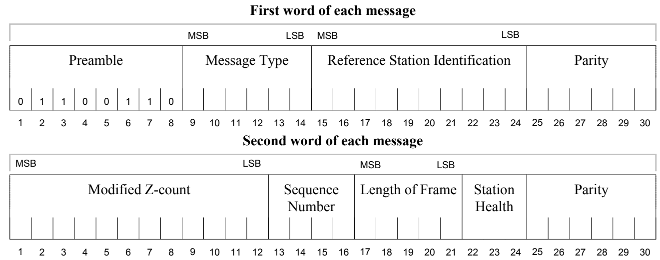

Figure II.2 – RTCM Message Header.

The header includes a fixed preamble (01100110) and several other fields: the message type (6 bits), the reference station ID (10 bits), the parity of the first word (6 bits), the modified Z-count time (13 bits), the frame sequence number (3 bits), the length of the frame (5 bits), the station health (3 bits) and the parity field (6 bits) of the second header word. The modified Z-count represents the reference time for the differential data messages. The sequence number varies between 0 and 7 and increments by one every time a new message header is generated. The length of frame indicates the size of the message (in RTCM words).

III. Design and Implementation

The developed distributed system performs two main tasks: the establishment of the Internet data links between DGPS base stations and the ISEP *campus* and the *campus*-wide DGPS data dissemination.

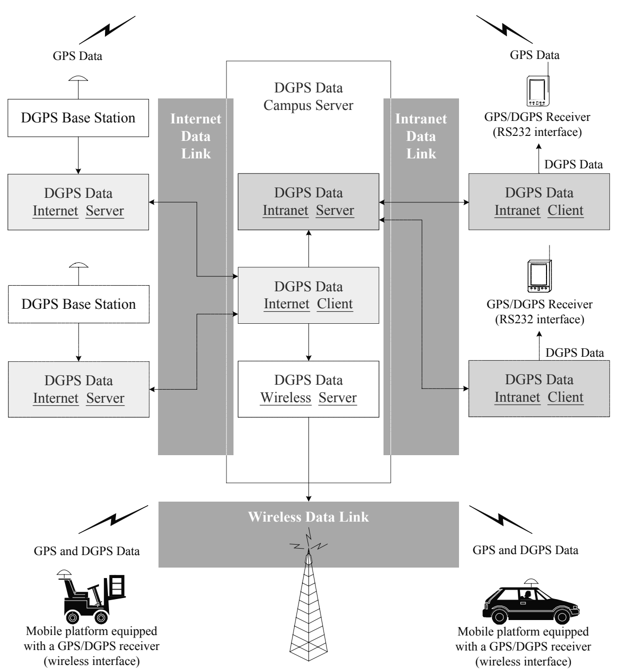

Figure III.1 – Architecture of the Application.

The overall application (Figure III.1) is a three-tier client/server distributed application where. The first tier – the client tier – represents the end client applications (wireless or Intranet clients located within the *campus*). The intermediate layer – the *campus* server – fetches and disseminates the

DGPS data for the end client applications. The third layer – the servers of DGPS data – acts as the data provider layer to the intermediate layer.

The first and third layers are insulated. This approach prevents the potential congestion of the data source servers and allows the adoption of different transport protocols between the first and second layers and between the second and first layers. The application provides three types of data links: Intranet and wireless data links – between the first and second layers – and Internet data links – between the second and third layers.

Additionally, we also implemented two types of data transmission: the standard byte stream and a new frame format. Whereas the byte stream was kept for compatibility reasons, the new frame format was designed to improve the reliability and quality of the service provided.

A. Data Transmission

The data can be transmitted between layers using either frames (frame mode) or, simply, sets of bytes (raw mode).

In raw mode, the byte stream generated by the station is transmitted by the server application (at the same rate it is generated by the DGPS base station) without any additional processing or verification. This latter mode was implemented in order to provide compatibility with other existing end-user Internet DGPS data clients (for example, the client software provided by [5] and found in [14]).

In frame mode, once a complete, error free RTCM message has been received by the server application, a data frame containing the individual RTCM message and other additional data is created and transmitted. In order to obtain a RTCM message from the information generated by a DGPS base station, the server application has to process the received data. The DGPS base station outputs a continuous byte stream via the serial interface that must be collected, decoded and assembled into valid RCTM messages. The byte stream received through the serial interface needs appropriate processing for several reasons:

1) Each one 8-bit byte (ANSI byte) contains one 6-bit RTCM byte. The two most significant bits of each 8-bit byte (the 2 non-RTCM bits) should contain the space and mark symbols (01), respectively.

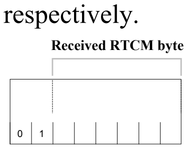

Figure III.2 – Received RTCM Byte.

As a result, the first processing step extracts, if the two most significant bits contain the expected space and mark symbols, the received RTCM byte from the ANSI byte.

2) The RTCM byte is generated by the base station according to the "most significant bit first" rule. However, since the ANSI standard for serial communications specifies that the least significant bit is the first one to be sent, a byte "roll" operation has to be performed.

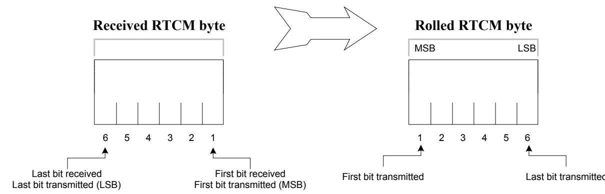

Figure III.3 – RTCM Byte Roll Process.

3) The obtained RTCM bytes still need to be assembled into RTCM words, which have, in turn, to be checked for parity and decoded according to the GPS signal messages algorithm.

4) Finally, the RTCM words have to be grouped into RTCM messages. Once a RTCM word with a correct preamble is detected, the assembling of a new RTCM message starts. This last step includes determining the length and the modified Z-count time of the incoming RTCM message.

When a whole RTCM message is received, the data frame containing the RTCM message can be created and sent over the established Intranet data link to the client.

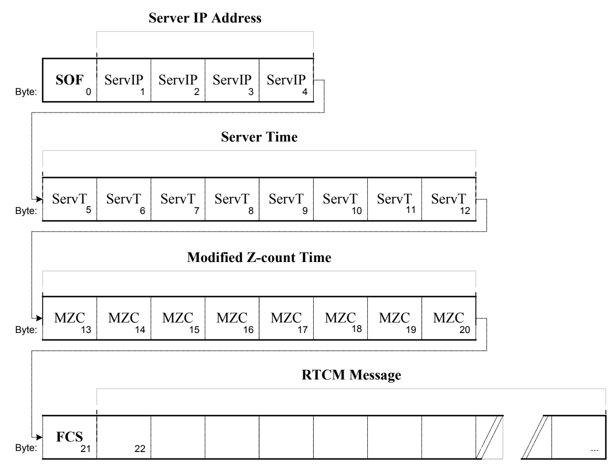

Figure III.4 – Data Frame.

Each data frame contains a header with a start of frame (SOF) byte, four bytes containing the DGPS server IP address, eight bytes holding the server time (ServT) at the moment the frame is created, eight bytes with the RTCM message modified Z-count time (MZC), a frame check sequence (FCS) byte and, finally, the RTCM message.

In frame mode, the receiving module is immediately capable of verifying the quality of the data link transmission as well as the age of the messages being received. If the data frames were transmitted without errors and the messages they hold are still applicable, the data frames are forwarded to the next unit. Additionally, since the frame header includes the IP address of the DGPS source, it is possible to establish links with multiple remote DGPS sources and decode them independently.

Frame mode requires that all platforms involved have a common time reference. This is achieved by ensuring that the platforms where the modules of the application execute are clients of the same NTP[1] server.

[1] Network Time Protocol.

B. *Internet Data Link Application*

The Internet link is accomplished through a two-tier client/server application. The server application is installed in a host at the DGPS base station and is continuously fed by the DGPS data generated by the DGPS base station.

The interface between the DGPS base station equipment and the DGPS data link server application is controlled by the DGPS base station equipment and consists of a serial (RS232) interface.

The implemented DGPS Internet Data Link provides two types of data links: a full-duplex, point-to-point, connection-oriented link and a simplex, point-to-multipoint, connectionless link. While the first link relies on the transport layer's Transmission Control Protocol (TCP) to provide a reliable communication service, the second type of link uses the transport layer's User Datagram Protocol (UDP) to provide a multicast message-oriented service. Additionally, both links allow multithreading, i.e., it is possible to use the server-side application to provide simultaneously DGPS Internet data links to multiple clients.

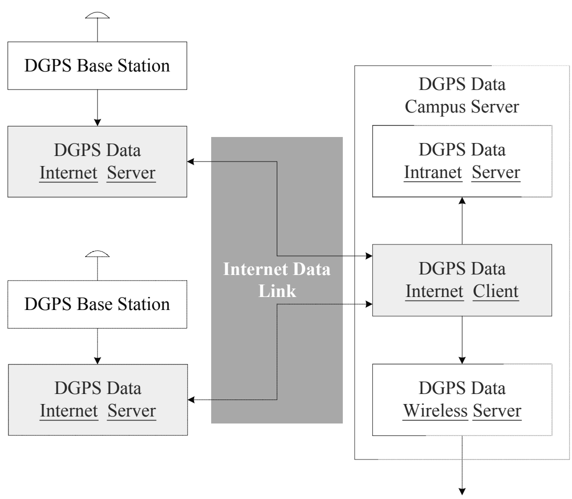

Figure III.5 – Internet Data Link Application.

In our case, since we intend to use multiple DGPS data sources, there will be several server-side applications running on hosts located at the premises of each DGPS data provider. Each server-side application data link is uniquely identified by its port and IP address. When the service link is supported by TCP, the IP address is the host IP address but when the service link supported by UDP, the IP address is the selected class D IP address (class D IP addresses are in the range 224.0.0.0 to 239.255.255.255, inclusive). The port number assigned by the Internet Assigned Numbers Authority (IANA) for the dissemination of DGPS correction data is port 2101.

C. *Campus-wide DGPS data Provider*

The *campus*-wide DGPS data provider disseminates data both via a radio beacon and via the *campus* Intranet. We chose to implement both services because we intend to use GPS/DGPS receivers with a DGPS data wireless input interface and with a RS232 DGPS input interface. In this latter case, a DGPS Data *campus* client must be installed, for example, in a laptop computer, to receive the correction data from the *campus* server and to forward it via the RS232 interface to the GPS/DGPS receiver.

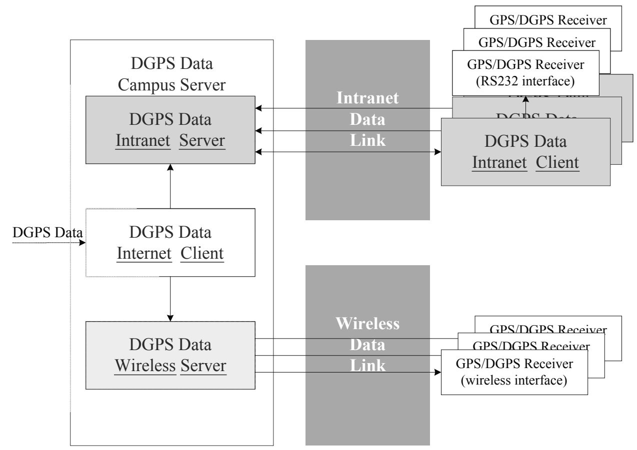

Figure III.6 – Architecture of the *Campus*-wide DGPS data Provider.

The DGPS data *campus* server is composed of three main units: the data input, the Intranet server and the wireless server modules. The data input module has already been described as the client-side module of the Internet data link application.

The DGPS data *campus* server receives the DGPS data directly from the DGPS Internet data link client and verifies the quality of the transmission and the age of each RTCM message. If the data frame is error free and the message is still applicable, the data is immediately forwarded to both Intranet and wireless modules in order to minimize the transmission delay. The transmission delay is critical since the final accuracy depends on the age of the correction data.

1) *Intranet Campus Server*

The Intranet server module receives the data frames containing the RTCM messages and multicasts them to all Intranet clients that joined the specified multicast group. Currently, the datagrams time-to-live (TTL) parameter is set to one (just for the Electrical Engineering Department sub-network).

The implemented DGPS Intranet Server establishes point-to-multipoint, message-oriented type of communication. The distributed application relies on the transport layer User Datagram Protocol (UDP) to provide a multicast service within the *campus* Intranet. Although UDP has no flow control mechanism, it is a message-oriented protocol, i.e., provides dynamic allocation of network bandwidth. In our case, since we need to establish simultaneously several connections within the local *campus* network, we adopted a multicast type of communication.

2) *Wireless Campus Server*

The most popular method for the transmission of DGPS correction data is via a radio beacon. In our case, the client application receives the DGPS corrections via the Internet link from the DGPS base stations and feeds them to the wireless server.

The role of the wireless server is three fold: first, it formats and buffers the DGPS messages, then, it modulates the data onto the transmitter carrier and, finally, broadcasts the resulting data.

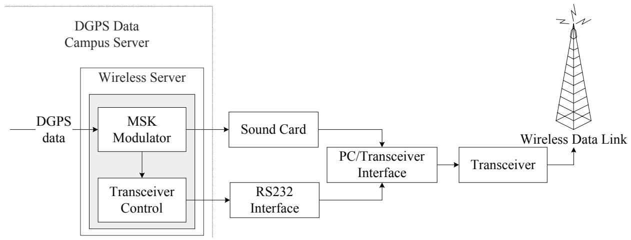

Figure III.7 – Wireless Server.

The data modulator receives the RTCM correction messages, encodes them as digital information using a Minimum Shift Keying (MSK) encoding algorithm, and forwards them to the computer sound card. Some special care must be taken in this processing since the RTCM protocol uses 30-bit length words and divides them into 6-bit length byte that are sent to the modulator in standard ANSI 8-bit byte occupying the six least significant bits. The modulator strips the start, stop and the two most significant bits from this byte and only transmits the six RTCM data bits over the air. At this point the data consists of just the RTCM SC-104 data protocol and the relationship between the start of a RTCM 30-bit word and an asynchronous ANSI byte has been lost.

Every time RTCM data is sent to the sound card, the transceiver control unit sends an automatic push-to-talk (PTT) command to the radio transceiver so that the RTCM data gets broadcasted.

The RTK data may require a minimum data rate of 4800 baud, as compared to a baud rate of 300 for the code phase tracking DGPS data.

The radio regulations governing the use of this band are specified in the International Telecommunications Union (ITU) Recommendation M.823 [11] and incorporate the RTCM SC-104 protocol [12].

3) Intranet Campus Client

The Intranet *campus* client is used to provide DGPS correction data to GPS/DGPS receivers with a serial DGPS input interface. In this case, the client-side application is used to establish the data link between the DGPS Data *Campus* Server and the RS232 interface of the receiver.

The client connects to the Intranet *campus* server module by creating a multicast socket and by joining the service multicast session (multicast IP address of the host and the application port of the service). Once the link is established, the DGPS data frames are received. Whenever a data frame is error free and the RTCM message it holds is not outdated, the message is immediately forwarded to the serial interface.

IV. Status and Results

After some research, we found three DGPS base stations in the vicinity (10 km radius area) of our *campus*. At the time, none of the proprietary entities was broadcasting DGPS data in a format compliant with standard DGPS/GPS receivers. The standard commercial DGPS/GPS receiver expects to receive DGPS data according to the Radio Technical Commission for Maritime Services Special Committee 104 (RTCM SC-104) protocol, either via a wireless or a RS232 interface.

One entity, herein called entity A, has a DGPS base station located at a distance of approximately 8 km to the northwest (NW) of our *campus*. The DGPS base station receiver has 12 single frequency (L1) tracking channels and generates RTCM V2.1 messages numbers 1 and 3 – pseudorange corrections. However, the radio broadcast frequency band (VHF) and the technology (self-organising time division multiple access system – SOTDMA) used are not compliant with standard GPS/DGPS receivers.

Entity B runs a DGPS base station located at approximately 6 km to the south (S) of our *campus* and was collecting DGPS data only for post-processing (12 hours RINEX data files). Base station B has 12 dual frequency (L1 and L2) tracking channels and is capable of outputting RTCM V2.1 and V2.2 messages numbers 1, 2, 3, 9, 18, 19, 20, 21 and 22 – pseudorange and real time kinematic corrections. Currently, as a result of this project, base station B is already generating real time DGPS data (RTCM V2.1 and V2.2 messages numbers 1, 2, 3, 20, 21 and 22).

The third entity, the "Instituto para o Desenvolvimento Tecnológico" (IDT), is located at our *campus* and runs a DGPS base station equipped with a Trimble Pathfinder Pro XR GPS receiver with 12 single frequency (L1) tracking channels which can provide RTCM V2.1 messages numbers 1 and 3 – pseudorange corrections. When this project started, IDT provided only near real time data (hourly RINEX data files for post-processing).

As we write this paper, we are running a series of tests using the IDT base station (which is located at our *campus*) as our primarily DGPS data source. We can provide now the results we obtained when using two Garmin GPS/DGPS receivers: a Garmin 176 (G176) and a Garmin 35 (G35). Both receivers accept DGPS correction via the serial interface. To compare the accuracy obtained differential positioning and with absolute positioning techniques, the receivers remained static through out the test and were positioned side by side. While the G35 only received GPS data, the G176, which was connected via the serial interface to a DGPS Data Campus Client, received both GPS and DGPS data. The DGPS data consisted only of pseudorange corrections.

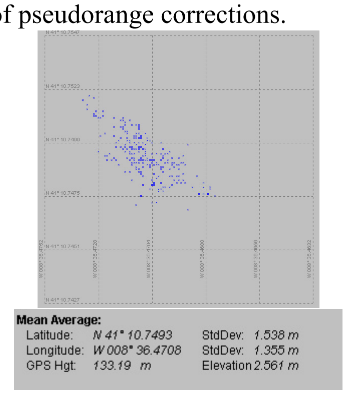

Figure IV.1 – G35 Absolute Positioning Results.

In the absence of differential corrections (Fig. 8), the latitude, longitude and elevation standard deviation values were 1.538 m, 1.335 m and 2.561 m. With the application of differential corrections (Fig. 9) during the same period of time, these values dropped to 0.899 m, 1.023 m and 2.042 m, respectively.

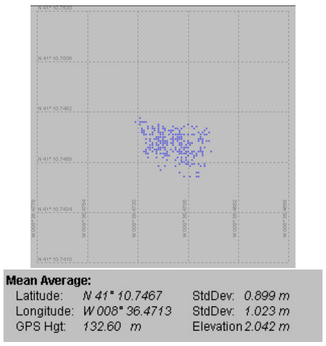

Figure IV.2 – G176 Differential Positioning Results.

While in the case of the G35 receiver, the mean average positioning values were 41º 10.7493 N, 8º36.4708 W and 133.19 m (elevation), in case of the G176, they were 41º 10.7467 N, 8º 36.4713 W and 132.60 m (elevation).

The positioning results obtained are shown using VisualGPS, a copyright tool for displaying GPS positioning data from VGPS [15].

Preliminary tests have also been performed with success at the premises of the base station of entity B. The station is already configured as a real time DGPS base station and is generating messages 1, 2, 3, 20, 21 and 22. However, since the network cable is not yet installed, we are not able to access the station data. Meanwhile, we are negotiating with entity A the access to their DGPS base station data.

The automatic control of the transceiver and the implementation of the PC/transceiver interface have been tested with success.

V. Related Work

The idea of disseminating RTCM corrections over the Internet in real time for precise differential positioning and navigation purposes was also investigated by W. Rupprecht [18]. In 1999, Rupprecht developed a DGPS data server called DGPSIP that disseminated DGPS data received through a radio interface at an average of 284 b/s. The radio was (and still is) normally tuned to POINT BLUNT, CA, Coast Guard transmitter: the server sends out a packet roughly every second with 35 bytes of data and 40 bytes of IP header. The DGPSIP is a multithreaded server, supports up to 64 concurrent connections and also transmits multicast UDP corrections (currently on 224.0.1.235 port 2101).

In 2002, the EUREF (European Reference Frame) which is a subcommission of IAG's (International Association of Geodesy) Commission X on Global and Regional Geodetic Networks, decided to set up and maintain a differential GNSS infrastructure (DGNSS) on the Internet using stations of its European GPS/GLONASS Permanent Network (EPN). The objective was to disseminate RTCM corrections over the Internet in real-time for precise differential positioning and navigation purposes [5]. The acronym for these activities is EUREF-IP (IP for Internet Protocol). DGNSS trial servers currently provide RTCM corrections as generated in a number of European countries. The EUREF provides since 2002 free client software to access the appropriate data streams. This implementation transmits the DGPS corrections through the Internet using the standard RTCM SC–104 protocol over TCP in raw mode.

More recently, several research teams have proposed and designed systems that use of GPRS as yet another support technology for the dissemination of DGPS data.

VI. Conclusion

In order to have access, within our *campus*, to DGPS correction data, we developed a three-tier client/server distributed application. The overall application provides three types of data links: Internet data links with multiple DGPS sources and Intranet and wireless data links between the *campus* server and the *campus* end clients.

The Internet data link module can work as a connection-oriented (TCP) or as message-oriented (multicast) client/server application and the data can be sent in frame mode or raw mode. Whereas the role of the server is to receive the DGPS data from the base station, to create a data frame and to forward it to the client, the client function is to verify the quality of the data link and to feed the received DGPS data to the DGPS *campus* server for immediate transmission.

The DGPS *campus* server implements a wireless DGPS data server and an Intranet multicast DGPS data server so that adequate support is provided both to GPS/DGPS receivers with and without a wireless interface. In the latter case, a client-side application was developed to receive and forward the information to the receiver's serial interface.

The work described in this paper implements more than just data links over the Internet between the DGPS data sources and the end client applications (two-tier client/server architecture). The separation between the transportation of DGPS data over the Internet from the dissemination of DGPS data within the *campus* provided by the three-tier client/server architecture adopted, prevents the potential congestion of the data source servers and allows the adoption of different transport protocols between the first and second layers and between the second and first tiers. Last but not least, the transmission of DGPS data using the proposed frame mode allows the simultaneous connection to multiple data sources, increasing the reliability of the system, and prevents the dissemination, within the *campus*, of outdated messages and of messages that suffered unexpected transmission errors.

So far, we have been able to verify that the implemented functionalities are working and that the data collected supports this claim – the service provides low-cost support for accurate outdoor *campus* navigation tasks.

Our current work is focused on testing and evaluating the system herein described.

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