Real Time Internet DGPS Service

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ABSTRACT

The accuracy of the Navigation Satellite Timing and Ranging (NAVSTAR) Global Positioning System (GPS) measurements is insufficient for many outdoor navigation tasks. As a result, in the late nineties, a new methodology – the Differential GPS (DGPS) – was developed. The differential approach is based on the calculation and dissemination of the range errors of the GPS satellites received. 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 establishes Internet links with remote DGPS sources and 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 (submetric) outdoor navigation tasks.

Keywords: Differential GPS, Internet and Distributed Systems.

1. INTRODUCTION

The need to improve the accuracy of the position readings obtained with standard Global Positioning System (GPS) receivers in outdoor navigation tasks carried at our *campus* led to the research and development described in this paper.

The typical solution to improve the accuracy of GPS measurements is the joint use of Global Positioning System data and Differential Global Positioning System 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 three-dimensional position, velocity and time GPS data to users is guaranteed by the NAVSTAR Global Positioning System (GPS) developed by the U.S. Department of Defense since December 8th 1993, the same is not true with appropriate DGPS data sources. The availability and adequacy of DGPS data sources depends, not only, on the existence of a network of terrestrial DGPS base stations, but also, on the appropriate coverage of the area under consideration, i.e., for each satellite signal received by the user's mobile GPS/DGPS receiver, a DGPS message containing the satellite's pseudorange correction data should be provided.

Although we found three DGPS base stations in the vicinity (10 km radius area) of our *campus*, none of the proprietary entities was, at the time, 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 an air 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. 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. 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. When this project started, IDT provided only near real time data (hourly RINEX data files for post-processing).

In order to convert these three data sources into usable real time DGPS sources the base stations need to be reconfigured, appropriate applications installed and the necessary infra-structures implemented. To achieve our goal, we chose to establish Internet data links between the DGPS base stations and the *campus* and, then, to implement a *campus*-wide DGPS data provider. The Internet data links are provided by a distributed (client/server) application. The server-side application runs on a host machine located at the DGPS base station premises. The client-side application is the data input module of the *campus*-wide DGPS data provider, i.e., runs on a host located at the *campus*. The role of the server is to receive the DGPS data from the base station and to forward it to the client. On the other end, when the client receives the DGPS data, the data becomes immediately available on the *campus* DGPS data provider for dissemination. The service provided by the overall distributed system is expected to provide support for *campus* outdoor navigation tasks with submetric accuracy.

This paper describes in detail this project. Section 1 introduces the reader to our motivation 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.

2. 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). Both systems provide continuous, worldwide, three-dimensional position, velocity and time information to users equipped with appropriate receivers. 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.

NAVSTAR Global Positioning System

The NAVSTAR Global Positioning System (GPS) was developed by the U.S. Department of Defense and has been fully operational since December 8th 1993. The GPS is composed of three segments: the space segment — a constellation of 24 satellites — which broadcasts the necessary data, the ground segment — a network of ground stations — which monitors and controls the operation of the satellite constellation, and the user segment — a set of end-users with appropriate receiving equipment — which establish their current position, velocity and time based on the information received from the satellites.

The GPS provides two positioning systems: the Standard Positioning System (SPS) for civil users and the Precise Positioning System (PPS) for U.S. military and government agency users. Until May 2nd 2000, the PPS provided an accuracy of at least 22.0 m (95%) in the horizontal plane, 27.7 m (95%) on the vertical plane and the SPS granted an accuracy of 100.0 m (95%) in the horizontal plane and 157.0 m (95%) on the vertical plane. In terms of UTC (USNO) time, the PPS provides an accuracy of 200 ns (95%) and the SPS 340 ns (95%) referenced to the time kept at the U.S. Naval Observatory (USNO). The PPS relied on the ability to decode two cryptographic features denoted as antispoofing (AS) and selective availability (SA) to guarantee, respectively, protection against ill-intentioned interferences and higher positioning accuracy. Since SPS users were unable to decode these features their readings were less accurate. On May 2nd 2000, the White House decided to stop the intentional degradation of the SPS accuracy and turned off the SA feature. Since this date, the SPS is free of human induced signal degradation.

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.

Differential Global Positioning System

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.

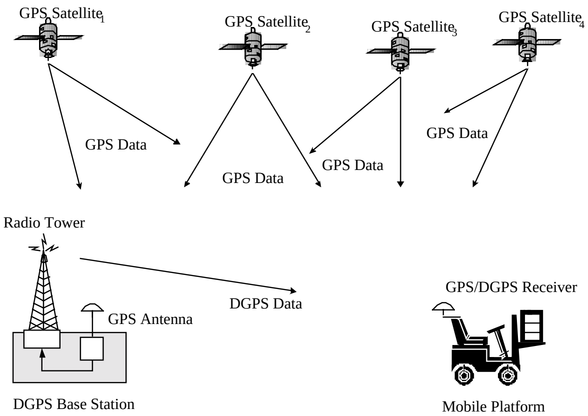

Figure 2.1 - Components of a DGPS system.

DGPS technology 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.

The differential corrections can be applied in real time or at a later time (post-processing). Typically, post-processed DGPS is used in land surveying and real time DGPS is intended for navigation purposes. This paper is concerned with real time DGPS data dissemination for navigation purposes.

Real Time DGPS can be implemented through terrestrial radio beacons, satellite constellations and, more recently, via the Internet. 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 and is intended for standard commercial DGPS/GPS receivers.

The first and still most frequent type of DGPS data network is the coverage through radio beacons. In this approach, the DGPS base stations are wireless stations that broadcast the satellites range errors over a given geographic area, using a specific protocol called RTCM SC-104. Standard GPS/DGPS receivers correlate the DGPS messages with the GPS satellite data they are receiving, increasing the accuracy of the measurements obtained. Although the exact accuracy obtained depends on the distance between the receiver and the DGPS stations and on the arrival frequency of the DGPS messages, the current DGPS accuracy (after May 2nd 2000) is of submetric order, i.e., a receiver using frequently updated correction data transmitted by multiple DGPS stations can attain submeter accuracy. DGPS radio beacons modulate the carrier with the correction data and other information such as the health of the reference station and the identification of the transmitter. The modulation is Minimum Shift Keying (MSK), a special form of Frequency Shift Keying (FSK), and the modulation rate is usually 100 b/s or 200 b/s. The radio beacon system uses the LF/MF band: from 283.5 kHz to 315.0 kHz in Europe and from 285.0 kHz to 325.0 kHz in other parts of the world. The radio regulations governing the use of this band are specified in the International Telecommunications Union (ITU) Recommendation M.823 [12] and incorporate the RTCM SC-104 protocol [13].

3. 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.

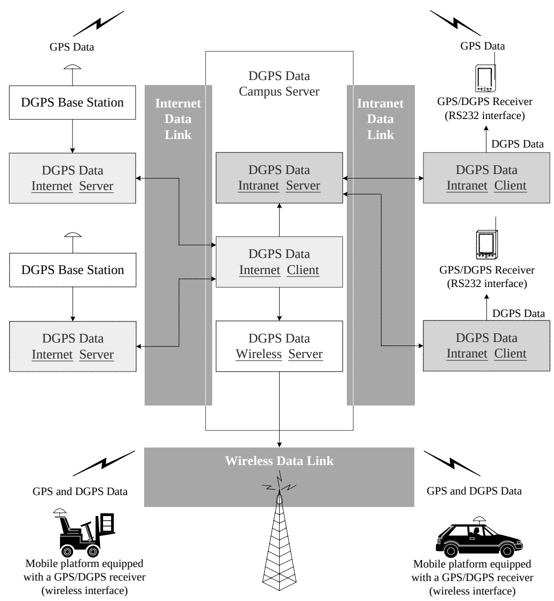

Figure 3.1 – System Architecture.

The overall application is a three-tier client/server distributed application. 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 third and second layers and between the second and first layers. The application provides three types of data links: the Internet data links – between the third and the second layers – and the Internet and wireless data links – between the second and the first layer.

RTCM Messages

The RTCM SC-104 protocol (V2.1 and V2.2) defines 33 types of messages of a total set of 64 possible messages. We will now present the generic characteristics of a RTCM message (for details about the different message types and contents please consult [13]).

RTCM messages are made of RTCM words and each RTCM word contains five RTCM bytes. Since a RTCM byte is a 6-bit byte, a RTCM word is 30-bit long. A RTCM word accommodates 24 bit of data and 6 bit of parity.

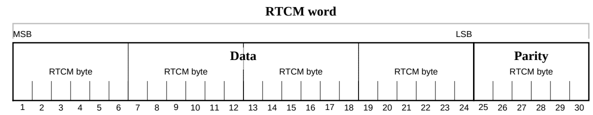

Figure 3.2– RTCM Word.

The parity information is used, not only, to guarantee the integrity of the data transmitted but, also, to encode the 24 bit of data of the following RTCM word – the data in a RTCM word is encoded according to the two last parity bits 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 [7]. 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.

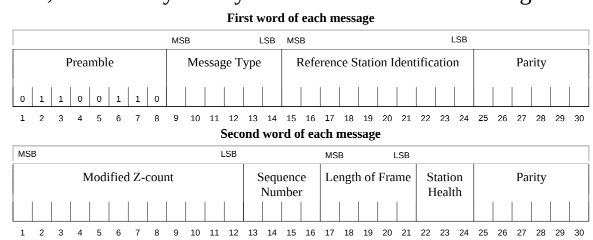

Figure 3.3 – RTCM Message Header.

The header includes a fixed preamble (01100110) and several other fields: the message type (6 bit), the reference station ID (10 bit), the parity of the first word (6 bit), the modified Z-count time (13 bit), the frame sequence number (3 bit), the length of the frame (5 bit), the station health (3 bit) and the parity field (6 bit) 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).

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.

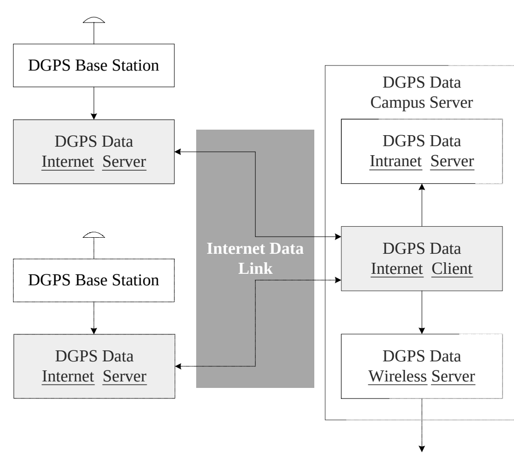

Figure 3.4 – Internet Data Link Application.

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 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 multiplexing, i.e., it is possible to use the server-side application to provide simultaneously DGPS Internet data links to multiple clients (multithreaded server).

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.

Data Transmission: The developed Internet Data Link Application allows data transmission over TCP (unicast) and UDP (multicast). The data transmission can be implemented using data 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 mode was implemented in order to provide compatibility with other existing end-user Internet DGPS data clients.

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.

The DGPS Data *campus* server expects to receive DGPS data in frame mode.

Frame Mode: When in frame mode, the server application creates a data frame for each RTCM message received. 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 two non RTCM-bit) should contain the space and mark symbols (01), respectively.

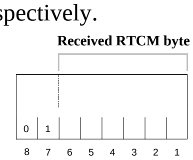

Figure 3.5 – Received RTCM Byte.

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 was 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.

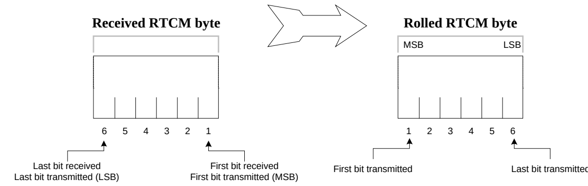

Figure 3.6 – RTCM Byte Roll Process.

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.

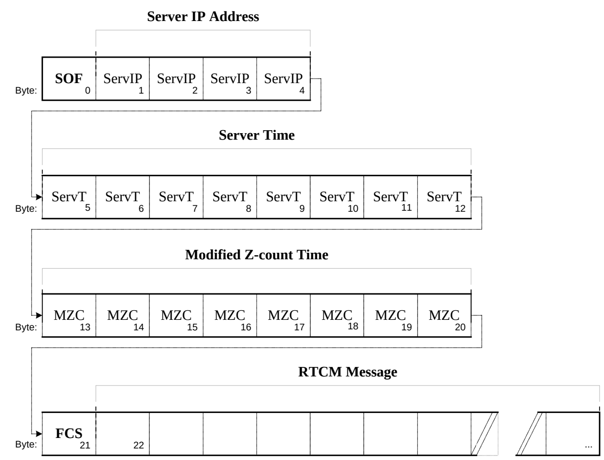

Figure 3.7 – Data Frame.

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

In frame mode, the client-application receives the frames containing the RTCM messages and 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 DGPS data *campus* server application. Additionally, since the frame header includes the IP address of the DGPS source, the client-side application can 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.

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

[1] Network Time Protocol.

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.

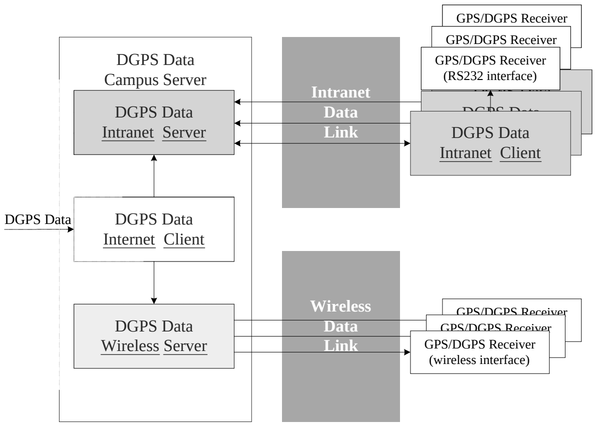

Figure 3.8 – Architecture of the *Campus*-wide DGPS data Provider.

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. The data is immediately forwarded to both server Intranet and wireless modules in order to minimize the transmission delay. The transmission delay is critical since the correction data is only usable by the receivers if they do not exceed the GPS update interval rate (1 update per second).

Intranet *Campus* Server: The Intranet server module receives the data frames containing the RTCM messages, verifies the quality of the transmission and the age of the RTCM messages. If the data frames are error free and the messages are still applicable, the data frames are forwarded to all clients connected. The Intranet server multicasts DGPS data frames to all Intranet clients that join the specified multicast group at the application port created for this service. 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 simplex, 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.

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.

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 eight 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.

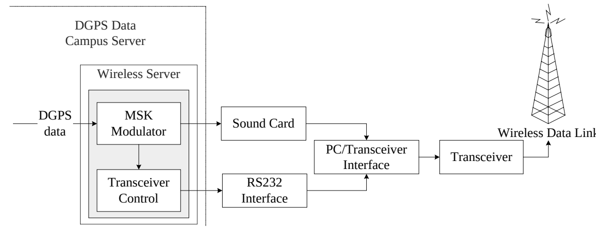

Figure 3.9 – Wireless Server.

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 corrections encoded as MSK and are then modulated onto the carrier of the radio beacon. MSK encoding results in approximately a ±25 Hz shift in the carrier frequency of the radio beacon (at 100 b/s). During normal operation the minimum field strength of the DGPS broadcast signal will be 75 mV/m in the specified coverage area, at a transmission rate of 100 b/s.

Intranet *Campus* Client: The Intranet *campus* client is used to provide DGPS correction data to GPS/DGPS receivers with a RS232 input interface for DGPS data. 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 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 RS232 interface.

4. STATUS AND RESULTS

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 primary DGPS data source. 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 Internet connection is not yet installed, we are not yet able to use it. Meanwhile, we are negotiating with entity A the access to their DGPS base station data. Our interest in accessing multiple data sources results from the fact that each DGPS base station generates DGPS correction data regarding the group of satellites it listens to. In order to guarantee the best possible accuracy we need to get range error data for as many GPS satellites as possible, i.e., from as many DGPS base stations as we can.

Additionally, we have also used existing on-line DGPS servers located in other parts of the globe. We were able to establish successful data links between our mobile GPS/DGPS receivers and these remote data sources. Although the data received was not appropriate for our *campus* (the received corrections were for satellites out of sight), it was possible to verify the compatibility between systems.

We are running intensive tests, collecting system performance indicators and hope to be able to provide a detailed system evaluation in a near future. So far, we have been able to verify that the implemented functionalities are working and that the data collected supports this claim.

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

5. 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 byte of data and 40 byte 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 [6]. 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.

6. 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-users applications.

The work described in this paper implements more than just standard data links over the Internet between the DGPS data sources and the end-user applications (existing two-tier client/server architectures). The adopted three-tier client/server architecture implements the transportation of DGPS data over the Internet and the dissemination of DGPS data within the *campus* as separate tasks. 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 tiers. Last but not least, the transmission of DGPS data using the proposed frame mode allows the simultaneous connection to multiple data sources and prevents the dissemination, within the *campus*, of outdated messages and of messages that suffered unexpected transmission errors.

The service provided by the overall distributed system is expected to provide low-cost support for accurate (submetric) outdoor *campus* navigation tasks. Our current work is focused on testing and evaluating the system herein described.

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