IMPLEMENTATION OF A CAMPUS-WIDE DGPS DATA SERVER

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ABSTRACT

Although the Navigation Satellite Timing and Ranging (NAVSTAR) Global Positioning System (GPS) is, *de facto*, the standard positioning system used in outdoor navigation, it does not provide, *per se*, all the features required to perform many outdoor navigational tasks. The accuracy of the GPS measurements is the most critical issue. The quest for higher position readings accuracy led to the development, in the late nineties, of the Differential Global Positioning System (DGPS). The differential GPS method detects the range errors of the GPS satellites received and broadcasts them. The DGPS/GPS receivers correlate the DGPS data with the GPS satellite data they are receiving, granting users increased accuracy. DGPS data is broadcasted using terrestrial radio beacons, satellites and, more recently, the Internet. Our goal is to have access, within the ISEP campus, to DGPS correction data.

To achieve this objective we designed and implemented a distributed system composed of two main modules which are interconnected: a distributed application responsible for the establishment of the data link over the Internet between the remote DGPS stations and the campus, and the campus-wide DGPS data server application. The DGPS data Internet link is provided by a two-tier client/server distributed application where the server-side is connected to the DGPS station and the client-side is located at the campus. The second unit, the campus DGPS data server application, diffuses DGPS data received at the campus via the Intranet and via a wireless data link. The wireless broadcast is intended for DGPS/GPS portable receivers equipped with an air interface and the Intranet link is provided for DGPS/GPS receivers with just a RS232 DGPS data interface. While the DGPS data Internet link servers receive the DGPS data from the DGPS base stations and forward it to the DGPS data Internet link client, the DGPS data Internet link client outputs the received DGPS data to the campus DGPS data server application. The distributed system is expected to provide adequate support for accurate (sub-metric) outdoor campus navigation tasks. This paper describes in detail the overall distributed application.

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 the 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 corrections. 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 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 receiver, a DGPS message containing the satellite's pseudorange correction data is provided.

After some investigation we concluded that there are two DGPS base stations in a 10 km radius area of our campus. Although both base stations produce DGPS correction data, none of the proprietary entities is 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. In Europe, the air interface uses the LF/MF band (from 283.5 kHz to 315.0 kHz).

One entity, the Administração dos Portos do Douro e Leixões (APDL), has a DGPS base station located at the nearby Leixões harbour at a distance of approximately 8 km from the campus. The APDL's DGPS base station is a subcomponent of a much larger Vessel Traffic and Management and Information System (VTMIS) which, among other modules, includes a Vessel Traffic System (VTS) responsible for identifying and tracking vessels within the VTMIS controlled area (a circular area of approximately 60 km radius). The latter function – vessel tracking – relies on the Global Satellite Positioning System and on the referred DGPS base station to establish accurately the position of the ships. The radio transponder system adopted by the international maritime authorities to support ship tracking, ship-to-shore identification and ship-to-ship data transfer to assist in collision avoidance is called Universal Shipborne Automatic Identification System (AIS). The AIS broadcast system operates in the VHF maritime mobile band, supports the exchange of diverse ship information (identification, position, course, speed, etc.) and uses Self-organizing Time Division Multiplexing Access (STDMA) techniques. As a result, the AIS transponder installed at the harbour broadcasts the DGPS data over the STDMA data link over the VHF channels assigned by ITU. The two worldwide channels designated for AIS purposes at 1997 ITU World Radio Conference are channels 87B (161.975 MHz) and 88B (162.025 MHz).

In the case of the second entity, the DGPS base station equipment is working but the correction data is neither being broadcasted via a radio beacon nor via the Internet.

From this analysis results that both DGPS data sources are, from our point of view, unusable unless appropriate data links are implemented from the DGPS base stations to our campus. In the first case, although the DGPS data is broadcasted, the frequencies and the transmission format are not compliant with standard receivers. In the latter case, the data is simply wasted.

Currently, we are negotiating with both institutions to access the respective DGPS data sources. Our interest in accessing both sources results from the fact that each DGPS base stations 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.

To achieve our overall 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 server application. The Internet data link is provided through a distributed (client/server) application. The server-side application runs on a host machine located at the DGPS base station premises and the client-side application executes on a host locate at the campus. While the role of the server is to receive the DGPS data from the base station transponder and to forward it to the client, the client function is to feed the received DGPS data to the DGPS Data Campus Server for immediate broadcasting. The service provided by the overall distributed application is expected to provide support for accurate sub-metric outdoor campus navigation tasks.

This paper describes in detail the application under development. Section 1 introduces the reader to the problem, our motivation and goal. Section 2 provides a light description of the features of the GPS and DGPS systems. Section 3 presents the developed application. Section 4 describes the current status of the implementation and section 5 draws 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 with appropriate receiving equipment. In the near future, the European GALILEO satellite radio navigation system will be 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.

2.1 NAVSTAR Global Positioning System

The NAVSTAR Global Positioning System (GPS) was developed by the U.S. Department of Defense and is 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 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. While, until May 2nd 2000, the PPS had an accuracy of at least 22.0 m (95%) in the horizontal plane, 27.7 m (95%) on the vertical plane, 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). Until May 2nd 2000, 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.

2.2 DIFFERENTIAL GLOBAL POSITIONING SYSTEM

The permanent quest for higher position readings accuracy led to the development, in the late nineties, of a GPS subsystem called the Differential Global Positioning System (DGPS). By definition, the Differential GPS 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 receivers) and situated at precisely geo-referenced locations, to compute and broadcast the range errors of the GPS satellites received. 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 DGPS data coverage networks can be implemented through terrestrial radio beacons, satellite constellations and, more recently, via the Internet. While in the case of the 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 distributed applications. 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 DGPS/GPS 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 most frequent type of DGPS data network coverage 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 commercial DGPS/GPS receivers correlate the DGPS messages with the GPS satellite data they are receiving, granting users increased accuracy. Although the exact accuracy obtained depends on the distance between receiver and DGPS stations and on the arrival frequency of the DGPS messages, the current DGPS accuracy (after May 2nd 2000) is of sub-metric order, i.e., a receiver using frequently updated correction data transmitted by multiple DGPS stations can attain sub-meter 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 or 200 bit per second. 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 (1996), incorporate the

RTCM SC-104 protocol and allow the transmission of supplementary information (such as the DGPS correction signals).

The U.S. Coast Guard was a pioneer in the field of DGPS by promoting, implementing and operating, since 1996, a coastal network of DGPS stations equipped with radio beacons for marine navigation. Nowadays, DGPS networks are frequent all over the world and are used for air, terrestrial or marine navigational purposes.

3 Design and Implementation

The implementation of the proposed distributed system was decomposed in two main tasks: the establishment of the Internet data links between the DGPS base stations and the ISEP campus and the development of the campus-wide DGPS data server.

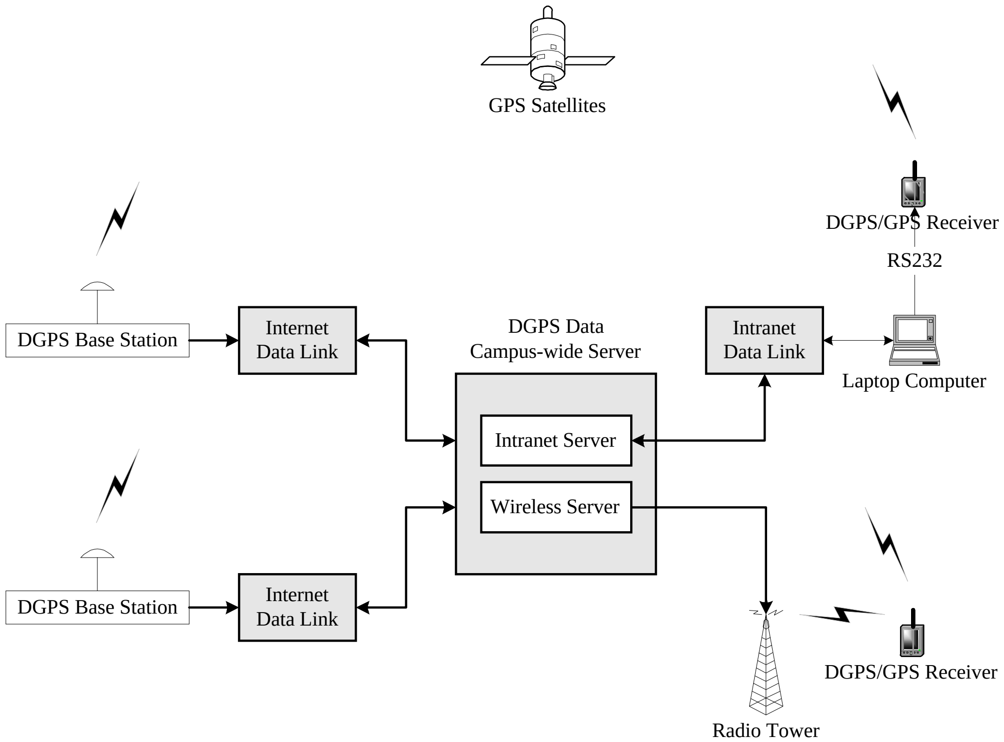

Figure 1 – System Architecture.

The Internet data links are established through a client/server application. The client-side is located at the campus and the server-side at the DGPS base station. The DGPS data campus server is, again, a client/server application. The service is provided to the ISEP campus users via a wireless link or through an Intranet data link that requires the installation of a client-side application.

3.1 DGPS 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 RS232 interface.

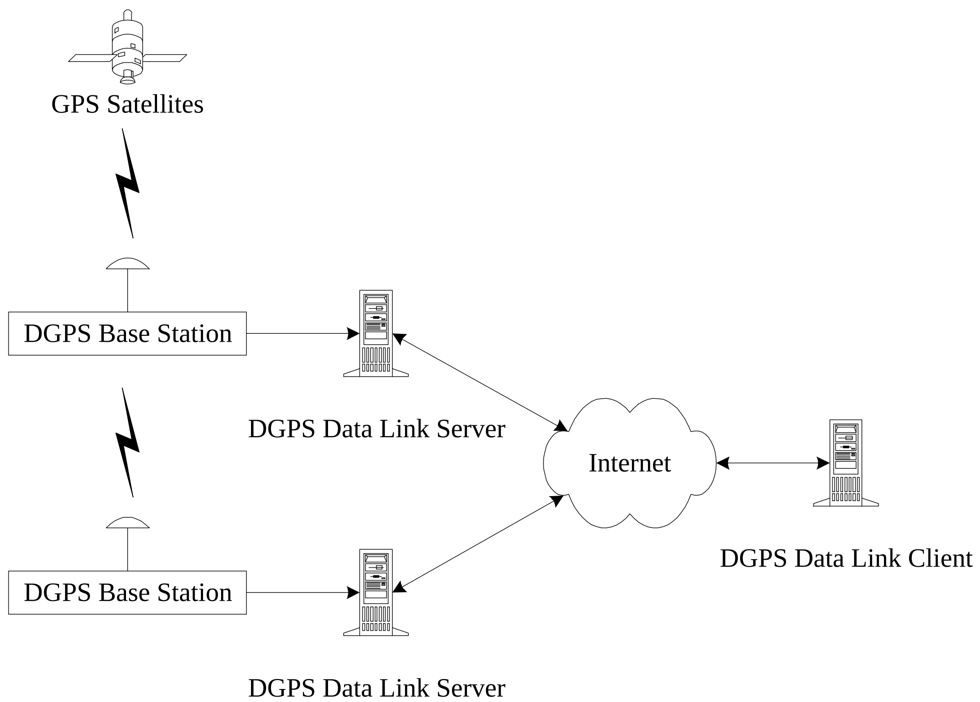

Figure 2 – DGPS Internet Data Link Two-tier Application.

The implemented DGPS Internet Data Link establishes a full-duplex, point-to-point, message passing type of communication. The distributed application relies on the transport layer's Transmission Control Protocol (TCP) to provide a reliable transmission of data. The reliability results from the fact that TCP is a connection-oriented protocol with an efficient flow control mechanism. Additionally, and since TCP allows multiplexing, it is possible to use the server-side application to provide DGPS Internet data links to more clients than just the ISEP campus client. The distributed application protocol is an extension of the RTCM-SC 104. While during DGPS data transmission the RTCM-SC 104 protocol is used, in the establishment of the link and in the closing of the link additional primitives are used.

In our case, since there are two DGPS data sources, there are two server-side applications running on hosts located at each DGPS base station premises. Each server-side application is identified by the specified application port and by the IP address of the host where it is running. The server-side application port corresponds to the port attributed to the TCP server socket created by the application to attend the clients. Although we will only need to establish one data link to each station, the server-side applications are designed to attend simultaneously multiple clients, i.e., they can be used to establish multiple Internet data links.

The client-side application, located at a host on the campus, is capable of establishing connections with multiple remote DGPS data servers, to receive the RTCM-SC 104 messages containing the DGPS data corrections and to forward them to the DGPS data campus server application.

3.2 DGPS DATA CAMPUS APPLICATION

The DGPS Data Campus application provides campus-wide DGPS data both via a radio beacon and via the campus Intranet. The idea is to be able to use DGPS/GPS receivers with and without a DGPS data air interface. The DGPS/GPS receivers without a DGPS data air interface have a RS232 DGPS input interface. In this latter case, a DGPS Data

Campus Client can be installed, for example, in a laptop computer to receive the corrections data and to forward it via the RS232 interface to the DGPS/GPS receiver.

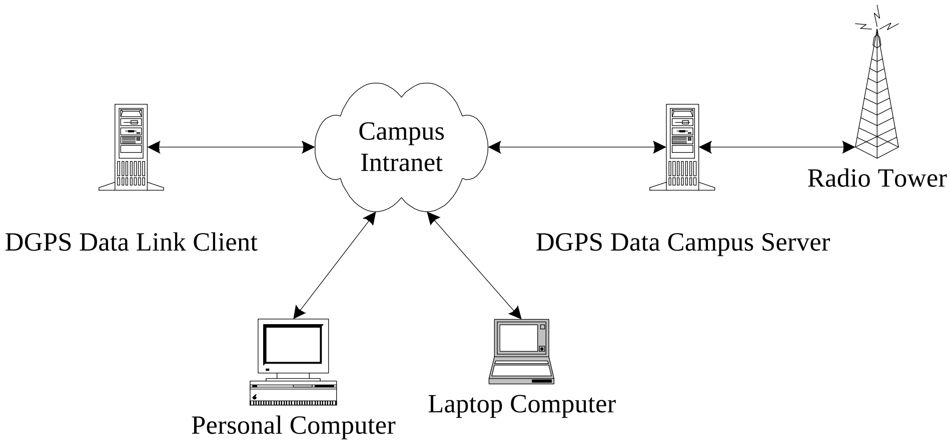

Figure 3 – DGPS Data Campus Application.

3.2.1 DGPS DATA CAMPUS SERVER

The DGPS Data Campus Server is composed of two functional units: the Intranet server module and the wireless server module. The DGPS data is received through a TCP client/server type of link between the DGPS Internet Data Link Client and the DGPS Data Campus Server.

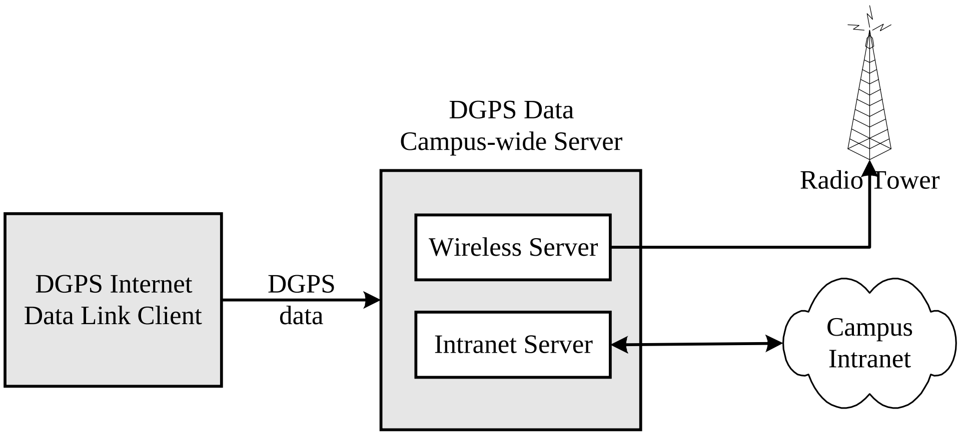

Figure 4 – DGPS Data Campus Server.

The information received from the DGPS Internet Data Link Client is immediately forward to both modules to minimize transmission delays. The transmission delays are 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). Whenever pseudorange corrections regarding the same satellite are received within the same update interval from different DGPS base stations, only the first one is broadcasted.

3.2.1.1 INTRANET SERVER MODULE

The Intranet server module receives the DGPS corrections in the RTCM SC-104 protocol and forwards them to all clients connected. The Intranet server multicasts

DGPS data in RTCM SC-104 protocol 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 full-duplex, point-to-multipoint, message passing 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.

3.2.1.2 WIRELESS SERVER MODULE

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.

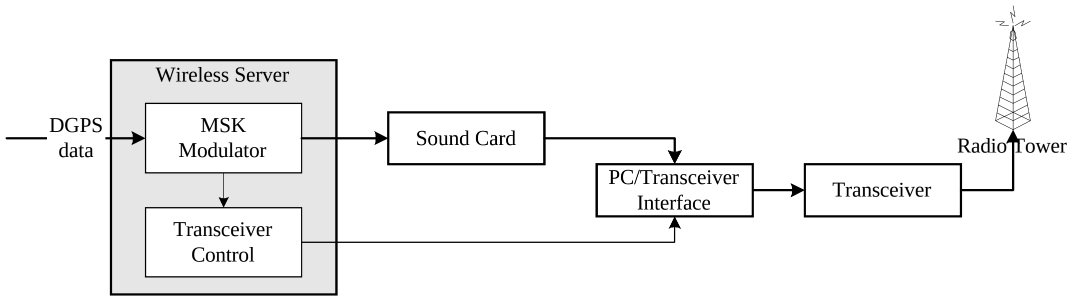

Figure 5 – Wireless Server Architecture.

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 bytes that are sent to the modulator in standard ASCII 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 SC-104 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 ASCII 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.

3.2.1.3 RADIO BEACON DATA LINK

The MSK radio beacons transmit between 283.5 kHz and 325.0 kHz, with typical geographic ranges from 160 to 500 km (the range of an individual transmitter is a function of power output, antenna height and efficiency, as well as the characteristics of the surrounding land). The broadcast data consists of a selected subset of the message types contained in the RTCM Special Committee No. 104, "Recommended Standards for Differential GNSS Service", Version 2.2, dated January 15, 1998 and referred in this paper as "RTCM SC-104".

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 bit per second). During normal operation the minimum field strength of the DGPS broadcast signal will be 75 microvolt per meter (μV/m) in the specified coverage area, at a transmission rate of 100 bit per second.

3.2.2 DGPS DATA CAMPUS CLIENT

The DGPS Data Campus Client is used to provide DGPS correction data to DGPS/GPS receivers without an air 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 DGPS Data Intranet Server 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 corrections received are immediately forwarded to the RS232 interface.

4 IMPLEMENTATION STATUS AND RESULTS

Currently, we are running a series of tests on the distributed systems developed. The installation of the first DGPS Internet Data Link between the Leixões harbour DGPS base station and the campus is expected to occur until July 2002. After this date we will launch the final tests and hope to be able to provide systems performance and overall application evaluation data. The installation of the second Internet Data Link depends on the answer of the proprietary agency. Meanwhile, the automatic control of the transceiver and the implementation of the PC/transceiver interface have been tested with success.

5 CONCLUSION

In order to have access, within the ISEP campus, to DGPS correction data, we developed two main modules: the Internet data link application and the campus-wide DGPS data server application. The Internet data link module is a connection-oriented client/server application where the server-side application runs on a host machine located at the DGPS base station premises and the client-side application executes on a host located at the campus. While the role of the server is to receive the DGPS data from the base station transponder and to forward it to the client, the client function is to feed the received DGPS data to the DGPS Data Campus Server for immediate broadcasting. The DGPS Data Campus Server is also implemented as a distributed application. The server-side application is composed of two main blocks: a wireless DGPS data server and an Intranet multicast DGPS data server so that adequate support is provided both to DGPS/GPS receivers with and without an air interface. In the latter case, a client-side application was developed to receive and forward the information to the receiver’s RS232 interface.

The service provided by the overall distributed system is expected to provide low-cost support for accurate (sub-metric) outdoor campus navigation tasks.

Our current work is focused on testing the application herein described.

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